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INSTRUCTION MANUAL
MODEL 351
PHASE METER

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WILTRON COMPANY
PALO ALTO, CALIFORNIA

INSTRUCTION MANUAL

MODEL 351

PHASE METER

FILE COPY

WILTRON COMPANY
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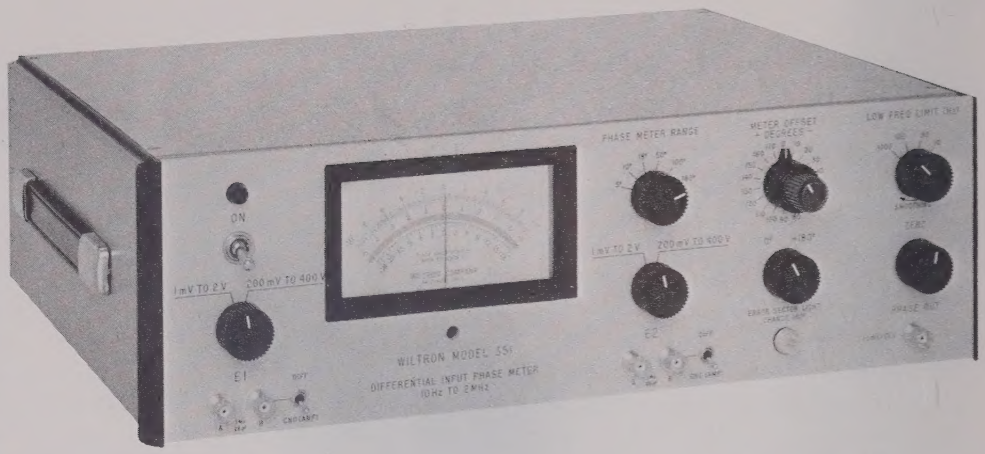

Figure 1-1

Front View

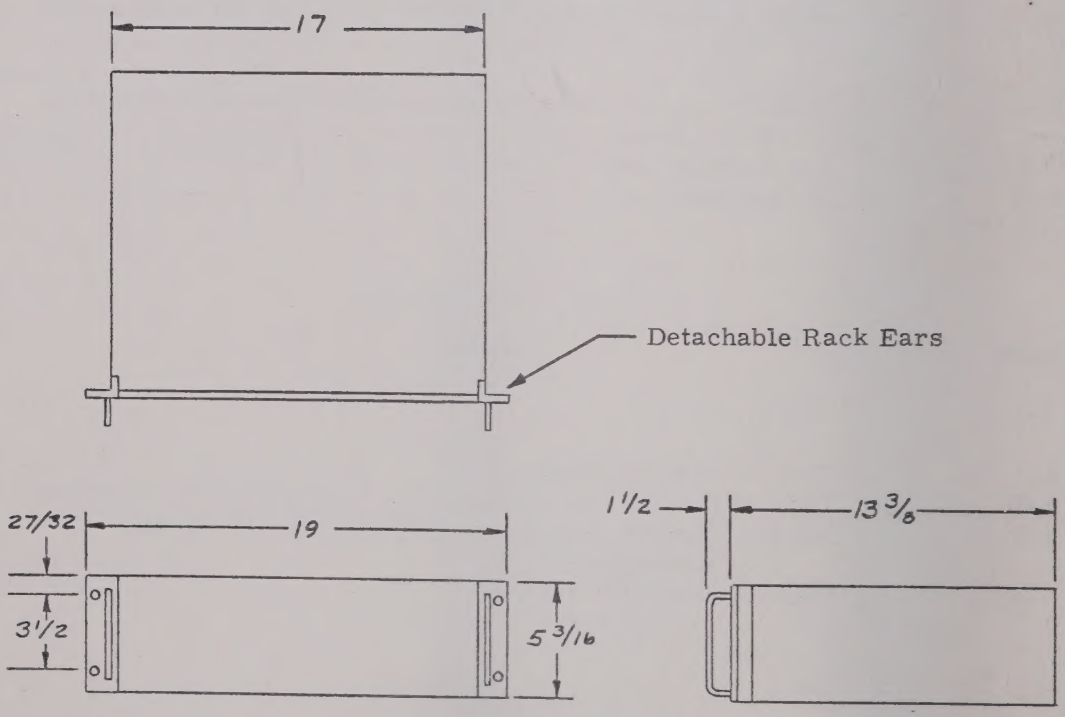

Figure 1-2

Outline Drawing

SECTION I
GENERAL INFORMATION

1-1. GENERAL INFORMATION

The WILTRON Model 351 Differential Input Phase Meter (Figure 1-1) is a precision, solid-state instrument used to measure the phase angle difference between a reference signal and a test signal having the same frequency. The measured phase angle is read directly in degrees on a precision 4" zero center meter. The phase meter can be connected to automated data handling equipment by means of an analog output connector, which provides a dc voltage directly proportional to the measured angle.

The phase meter accepts either single-ended or differential inputs within the frequency range of 10Hz to 2MHz with either input having an rms input level value from 1 mV to 400 v. The phase angle can be measured in either of two switch selected ranges centered about 0^{o} or 180^{o}.

The instrument is self-contained, including power supplies for 115/230 v ac, 50 to 400 Hz input power in a chassis 7" high, 19" wide, and 15" deep, suitable for bench use of mounting in a 19" wide rack. Weight of the unit is 20 pounds, shipping weight is 30 pounds.

1-2. MEASUREMENT TECHNIQUE

The two input signals whose phase angle difference is to be measured are shaped by separate, identical four-stage limiter amplifiers preceded by field effect transistor source followers. The two shaped signals are applied to separate identical Schmitt trigger stages, each of which generates a negative pulse at the exact time its input signal crosses the zero axis from positive to negative. These successive pulses turn on and off a bistable multivibrator, the average dc component of which is proportional to the time difference between successive zero axis crossings of the two input signals, and therefore proportional to the phase angle.

The output waveform is smoothed (filtered) to obtain the average dc component which is applied to the phase meter. The dc voltage, the analog of the phase angle measurement, varies between ±1.80 volts.

1-3. SPECIFICATIONS

Performance specifications for the phase meter are listed in Table 1-1. The performance specifications are met over a temperature range of 0^{o} to 50^{o}C after a warm-up and stabilization period of 15 minutes.

Table 1-1

SPECIFICATIONS

FREQUENCY RANGE	10 Hz to 2 MHz with useful performance above and below these frequencies.
INPUT LEVELS (Both inputs)	1 mV to 2 volts rms or 200 mV to 400 volts rms, selectable. DC blocking provided up to 400 volts.
INPUT IMPEDANCE	1 Megohm shunted by 26 ρF or, when used with Tektronix oscilloscope probes (Model P6006), 10 Megohms and 8 ρF. Differential impedance 2 Megohm shunted by 15 ρF or 20 Megohm and 4 ρF when using probes.
ACCURACY OF PHASE READING	-180° to $+180^{\circ}$ Range: Absolute accuracy = $\pm 0.1 \pm \frac{\phi}{180} \times 0.25^{\circ}$ Where ϕ is the angle being measured. 0 to 360° range: Relative accuracy is the same as for the -180° to $+180^{\circ}$ range shown above. For absolute accuracy on the 360° range when 0° standardization is set on the 180° range, then one must add the potential error of the 0°-180° switch which is (0.1 +0.3F) degrees where F is the test frequency in MHz. NOTE: This accuracy applies over the frequency range 100 Hz to 20 kHz after standardization at 1 kHz with input levels of 30 m V rms on the low input range or 6 volts rms on the high input range. Frequency and signal level effects out of this range are shown on page . The effects of waveform distortion is described in paragraph .
RANGE OF PHASE MEASUREMENT	360° - $(40F)^{\circ}$ where F is in MHz, e.g., when on the 0 - 360° range at 100 kHz the phase measurement range is 2° to 358°. To measure angles around 0° one would switch to the $\pm 180^{\circ}$ range.

Table 1-1 Cont.

PHASE OUTPUT VOLTAGE	10 mV per degree at the analog of phase voltage output. Range is -1.800 to +1.800 volts. A +180 phase shift (relative to the +180° to -180° range) is added to the phase output voltage when in the 0° to 360° position. Accuracy: Same as phase reading accuracy.
COMMON MODE REJECTION	A common signal to both terminals of an input is rejected at least 50 dB from a differential signal over the range 50 Hz to 100 kHz; 40 dB from 10 Hz to 1 MHz. Rejection maintained up to 2V or 400 V for sum of common mode plus differential signal.
ZERO CONTROL	Permits setting an absolute zero to take into account at a fixed frequency little differences in the length of input test leads. Without adjusting the zero control, the instrument "zero" will maintain within 0.5° from 100 Hz to 100 kHz.
RESPONSE TIME	Low Frequency Limit Switch Position / *Response Time 1 kHz — 40 mS 100 Hz — 400 mS 30 Hz — 1.3 sec 10 Hz — 4 sec *Approximate for 180° change to 0.1° of final value.

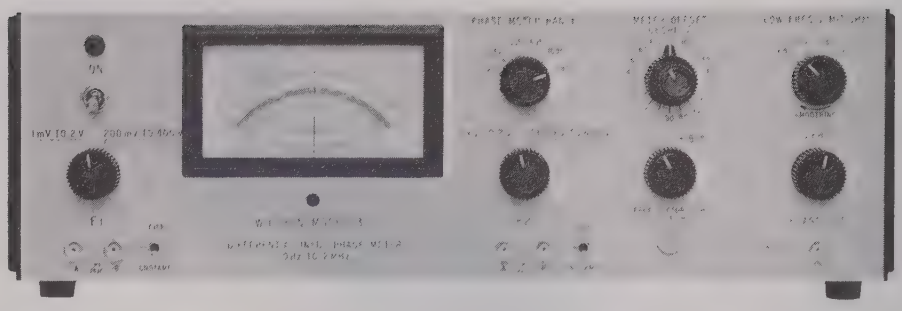

Figure 2-1

Front Panel View

Figure 2-2

Rear Panel View

SECTION II
INSTALLATION

2-1. RECEIVING INSPECTION

Make a careful visual inspection of the instrument on unpacking. Any apparent damage to either the instrument or the packing container should be reported to both the carrier and the factory.

2-2. MOUNTING

The instrument as received may be mounted in a 19 inch standard rack at a height most convenient for reading the meter. For bench use, the rack ears may be removed. A tilt stand is provided for raising the front panel to an angle which permits the greatest accuracy in reading the meter.

2-3. INPUT VOLTAGE AND FREQUENCY

A slide switch at the rear of the instrument allows selection of 115 or 230 volts input. (See Figure 2-2.) As shipped, this switch is in the 115 volt position. Check the switch position before operating. Input voltage should be held to within ±10% of the nominal value 115 or 230. 50, 60 or 400 Hz supply frequencies may be used.

2-4. FUSE PROTECTION

The instrument is fused with a 0.3 Amp Cartridge fuse at the rear. (See Figure 2-2.)

2-5. REAR CONNECTORS

As options, an additional analog of phase output and rear inputs to the E1 and E2 channels may be provided.

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SECTION III
OPERATION

3-1. FUNCTION OF CONTROLS

E1 and E2 1 mv to 2 v/200 mv to 400v selector switches: These two-position rotary switches, one above each set of input connectors, select one of two input ranges depending on the amplitude of input signals applied at E1 and E2. The ranges labeled are rms values of input voltage.

PHASE METER RANGE: This six-position switch selects meter range. Each position corresponds with a full scale meter range.

METER OFFSET DEGREES: The outer knob of this dual control offsets the meter phase reading in 10° steps from 0° to 170°. It does this by inserting a dc bias voltage in the meter circuit. Its function is to permit measurement of any phase angle on the most sensitive range of the instrument, that is, within ±5° of the offset value.

The inner knob of this control selects polarity of the offset, positive in left position and negative in right. Polarity of offset is equivalent to polarity of meter reading. For example, if meter reads +90°, offsetting to +90° will bring the meter reading to zero.

0 +180: This two-position control switches one of the two input signals from an in-phase ((0°) condition to an out-of-phase condition (+180°) with respect to the other. Use of this control makes it convenient to measure phase angles near 180° by moving their meter readings to near the zero part of the scale.

ERROR SECTOR LIGHT: The error sector light comes on when the angle being measured is close to 180° and there is an ambiguity between + and - 180°. If the error light comes on when the signals are known to be of sufficient amplitude, throwing the 0 + 180° switch will extinguish the light and move the meter reading into the proper phase range.

LOW FREQUENCY LIMIT: This control has four positions, minimum smoothing being the most counterclockwise. Moved clockwise, the control adds filtering to the output phase measurement signal. It is used to reduce the meter fluctuations which occur at low frequencies or in the presence of a noisy signal, and provides a smooth dc for digital voltmeter use.

ZERO: This control adjusts the phase reading to an arbitrary zero when any condition exists to cause a slight phase shift reading when the two input signals are known to be exactly in phase. This control can be used to compensate at a single frequency for unequal cable lengths in the E1 and E2 paths.

3-2. INPUT AND OUTPUT CONNECTORS

INPUT CIRCUITS: For normal, unbalanced circuit phase measurements, the input selector switches are used in the GND (AMP) position. In this position the 'B' input sockets are disconnected and the test signals are applied to the 'A' inputs.

For differential or balanced operation, the input selector switches are used in the 'DIFF' position. If desired, the E1 input signal can be unbalanced while the E2 circuit is balanced or vice versa.

PHASE OUT: The PHASE OUT connector provides a dc output signal proportional to the phase angle at 10 millivolts per

3-2. INPUT AND OUTPUT CONNECTORS (Cont.)

degree. This signal is not affected by the position of the METER OFFSET switch.

3-3. PRECAUTIONS TO TAKE FOR STABLE PHASE MEASUREMENTS

WILTRON Models 350, 351 and 355 Phase Meters have an input sensitivity of 1 mv on each channel and a bandwidth greater than 5 MHz. (The amplifiers have useful gain up to 30 MHz.) As a result, care must be taken that extraneous signals do not ride in with the desired test signals.

If the phase meter reading fluctuates or the meter occasionally pins itself to full scale, this indicates that spurious signals are reaching the trigger circuits of the phase meter. These may be line transients, spurious noise or RF signal pickup.

There are several ways in which unwanted signals can get into the phase meter:

a. Unshielded connection leads.

b. Ground loops.

c. Spurious output signals on the test oscillator or source.

d. Via the ac power line.

These effects can be minimized as follows:

a. Shield the input connections completely. Use low impedance signal lines. Add 0.00; uf disc capacitors from the input terminals to ground. If 1 mv sensitivity is not required, operate with the attenuator switches in the 200 mv position.

b. It is usually best to ground the phase meter and sources separately via their power cables but to use a common ac power line. However, some signal sources generate ground currents by thir ac line by-pass capacitors. In these cases an isolation transformer is suggested.

c. Several audio frequency oscillator designs from reputable companies have spurious noise signals and/or waveform kinks which can cause erratic phase meter readings. At WILTRON, Krohn Hite oscillators and -hp- Models 200 C/D and 651B are used. Other designs may be equally suitable.

d. RF bypass capacitors on the ac line input and electrostatic shielding in the power transformer make it very unlikely that any form of external line filter will be needed to remove normal levels of ac line interference, but in severe cases it may be necessary.

These precautions are not always necessary, depending upon location, etc., but they should be borne in mind in case of difficulty.

3-4. PHASE MEASUREMENT STEP-BY-STEP PROCEDURE.

1. Make the following front panel control settings:

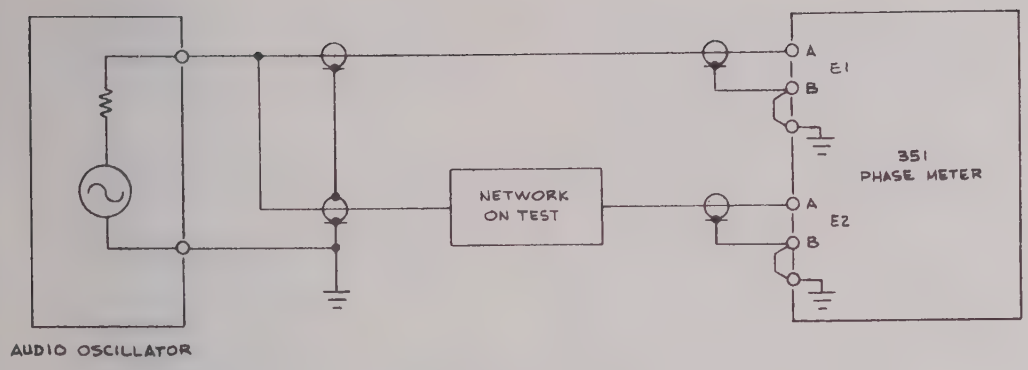
   PHASE METER RANGE switch to 5°.

   METER OFFSET switch to 0°.

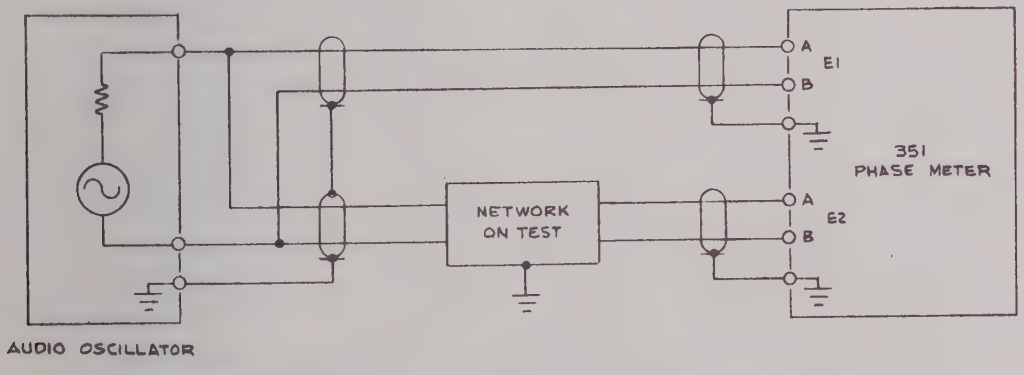
   0 +180° switch to 0°.

   OUTPUT SMOOTHING to the minimum (most counterclockwise) position.

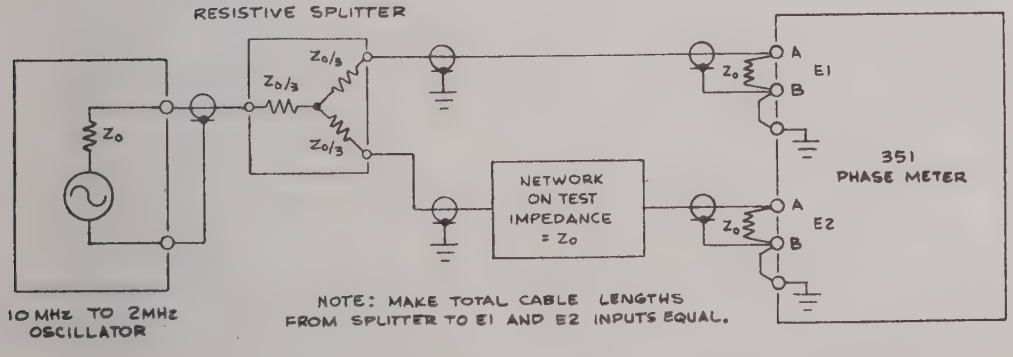
2. Determine the approximate voltage of the signals under test and set



UNBALANCED AUDIO PHASE MEASUREMENTS WITHOUT TERMINATION



OFF-GROUND UNBALANCED AUDIO PHASE MEASUREMENTS WITHOUT TERMINATION



AUDIO/VIDEO PHASE MEASUREMENT
IN UNBALANCED CIRCUITS WITH COMPLETE TERMINATION

FIG. 3-1

TYPICAL TEST SETUPS WITH
WILTRON MODEL 351 DIFFERENTIAL INPUT PHASEMETER

3-4. PHASE MEASUREMENT STEP-BY-STEP PROCEDURE (Cont.)

the input toggle switches for E1 and E2 to the range in which the test signals are most nearly centered.

3. Set up to divide an input signal into two paths and feed the same in-phase signal into both E1 and E2. A suggested test setup is shown in Figure 3-1. Adjust the ZERO control until the phase meter reads zero.

4. Set the PHASE METER RANGE switch to 180°. Introduce one test signal (reference) into E1 and the other into E2. Read the phase angle on the most convenient range.

5. For improved resolution in reading a large phase angle, set the METER OFFSET control to the 180° METER RANGE scale. If it is a positive (+) angle, introduce a (positive (+) offset; if a negative (-) angle, introduce a negative (-) offset. Then turn the PHASE METER RANGE switch to its 10° or 5° range.

6. Make the final phase reading which is the algebraic sum of the meter and the offset. Note that one reading may be positive and one reading negative, but if they are added, taking into account the sign, the resultant will be correct. A positive angle occurs when E2 leads E1. A negative angle occurs when E2 lags E1.

7. Set the LOW FREQUENCY LIMIT control to suit the input frequency. In the 10 Hz position, any frequency between 10 Hz and 2 MHz can be applied. In the 30 Hz position, any frequency from 30 Hz to 2 MHz can be applied, and so forth.

8. If the error sector light is on, do not make the reading, but change the position of the 0° knob to the +180° position and include that angle as part of the measured result.

9. If the meter reading is erratic, or if it pins to full scale occasionally, refer to Section 3-3.

3-5. MINIMIZING ERRORS DUE TO SIGNAL LEVEL VARIATIONS.

The most accurate measurements can be made by resetting the ZERO control using two in-phase signals at the input levels to be used during the test, as suggested in paragraph 3-2. If this is inconvenient and signal levels must be changed during the test, refer to Tables 5-2 and 5-3 in Section 5 for typical phase angle measurement errors when the signal levels are changed. For very accurate measurements, a table can be made for each individual phase meter, to show its particular zero change due to signal level variation. This table then can be used to correct the data.

3-6. MINIMIZING ERRORS DUE TO FREQUENCY VARIATIONS.

The most accurate measurements can be made by resetting the ZERO control using two in-phase signals of the same frequency as is to be used during tests. If this is inconvenient, and the input frequency must be changed during the test, refer to Table 5-3 in Section 5 for typical phase angle measurement errors when the input frequency is changed. For very accurate measurements, a table can be made for each individual phase meter, to show its particular zero change due to frequency variation. This table then can be used to correct the data.

3-7. ACCURACY LIMITATIONS IN MEASURING PHASE ANGLE OF DISTORTED WAVE FORMS.

The phase meter makes the phase measurement by detecting the fraction of a cycle between the negative-going zero axis crossing of the reference and the test signals. If the waveform of either signal is distorted so as to change its zero axis crossing (see Figure the phase angle reading will be in error. In testing configurations, where the signal levels on each channel are similar, this source of error can be removed by making two measurements, as described below.

As shown in Figure 3- measure the phase angle of the network under test connecting the reference input to E1 and the test input to E2. Note the phase angle reading A. Transpose the E1 and E2 inputs. Note the phase angle reading B. The true phase angle T is:

$$T = \frac{A + B}{2}$$

Making phase angle measurements in this manner permits accurate measurements with non-sinusoidal test signals. It also cancels errors due to incorrect setting of the ZERO control). More details on the effects of harmonics and spurious measurements are described below

HARMONIC DISTORTION - If there is harmonic distortion in the input signals, the readings can be in error by the following amount:

$$\text{Error in reading} = \frac{D}{100} \times 57°$$

where, D = harmonic distortion, in percent.

Thus, if 1° accuracy is required, the second harmonic distortion of the input signals must be less than 2%. If both inputs receive signals with harmonics, this is the limit of error in each channel. If the phasing of the harmonics is controlled, the errors may be eliminated by an in-phase relation. For example, a wave-

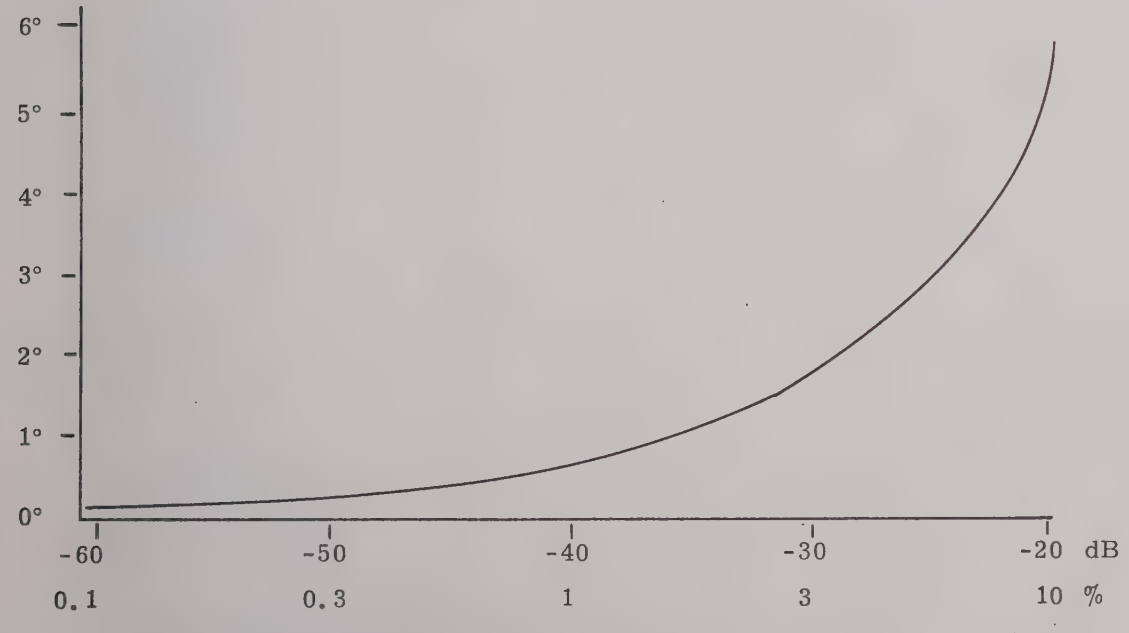


Figure 3-2. Phase Angle Error as Function of Harmonic Distortion

3-7. ACCURACY LIMITATIONS IN MEASURING PHASE ANGLE OF DISTORTED WAVE FORMS.

form rich in odd harmonics, such as a squarewave, will have no error. Odd order harmonics typically give less distortion because the harmonics tend to amintain a zero phase relationship with the fundamental.

To combat errors due to harmonics, use the method shown in Figure or use filters to eliminate the undesired harmonics. Use the graph, Figure 3-2, to determine the magnitude of error, or to establish the filter reduction factor for a desired accuracy.

NOISE - Errors due to non-coherent signals depend on both the magnitude and the frequency ratio of the non-coherent signals to the signals under test. An undesired signal that is at a fraction of the test frequency gives equal plus and minus errors and thus averages to zero with suitable filtering (smoothing). Error signals greater than 100 f (where f is the fundamental frequency of the test signal) will give an advancement of the zero crossing, resulting in a phase error of magnitude

$$\phi = \frac{e \times 57^\circ}{a}$$

where e is the magnitude of the error signal and a is the magnitude of the test signal.

For smaller frequency ratios, the average error will be an advancement between zero and $\frac{e \times 57^\circ}{a}$.

These errors are indicated when one test signal input has interfering signals and the other input is pure. If both signals have the same impurity, the errors will tend to cancel except in the coherent case. The same error limits, the same frequency ration dependence, and the two channel cancellation effects occur with random noise error signals as with harmonic distortion. The rms value can be used to calculate the limits.

Note that the use of a pair of identical low pass filters added at the inputs will remove the high frequency components, which are the principal error producers.

SECTION IV

THEORY OF OPERATION

4-1. OVERALL FUNCTIONAL DESCRIPTION.

Refer to the functional block diagram, Figure 4-2. Each input signal is processed through a source follower and amplifier having three limiting stages and one non-limiting output stage. A Schmitt trigger circuit produces a negative output pluse coincident with the negative going crossing of the average value of the amplified signal. These pulses cause the Phase Detector Multivibrator to change back and forth between its two bistable states. The average dc component of the resultant output wave from one side of the multivibrator is a measure of the time difference between the two negative-going zero crossings of the phase angle between them.

Waveforms from input terminals through the instrument to meter readings are sketched in Figure 4- 3 for phase angles of 0°, +90°, and 180°. The waveforms labeled TP9 and TP10 represent the inputs to the Schmitt triggers, and TP11 and TP12 the output pulses from the Schmitt triggers. TP13 represents the output square wave of the phase detector multivibrator, with Q302 switches between off and on states as shown by the MVBR INPUT waveform. The average dc component which causes the meter reading is shown by dash lines on the TP13 waveform.

Condition (d) Figure 4-3 results in an ambiguity for a phase angle at or near 180° because of the discontinuity in the output dc voltage inherent in any linear phase detector covering a full 360° range. See Figure 4-1. When the phase angle being measured is within a few degrees of 180° the error detector circuit senses this nearness and actuates the ERROR SECTOR LIGHT on the front panel. Switch the 0° +180° switch to the +180° position which selects the uninverted E2 signal, causing a 180° shift in the meter phase reading. Thus, angles in the vicinity of + of - 180 may be read near zero degrees.

4-2. OPERATIONAL SCHEMATIC DIAGRAMS.

Simplified schematic diagrams of each main section of the instrument, which illustrate the signal processing in greater detail, are included in Figures 4-4 through 4-8. Signal paths are shown by heavy lines and waveform shapes at the input and output of each stage are illustrated.

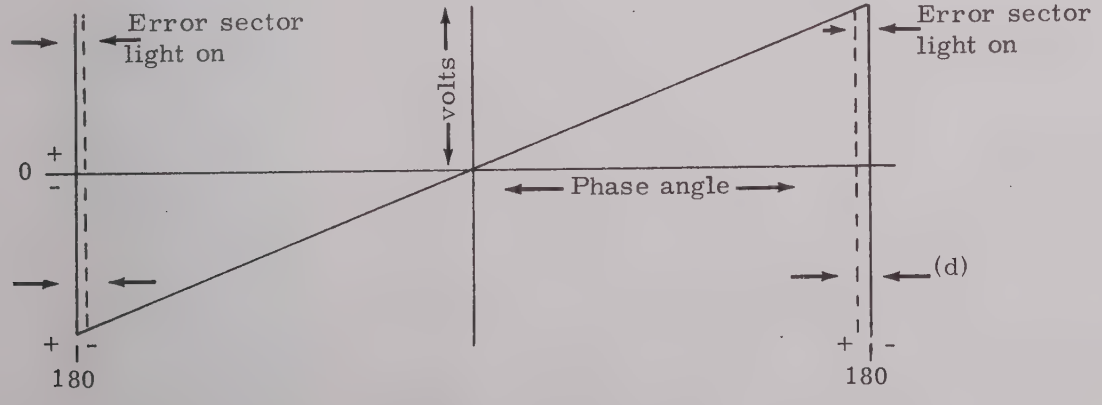
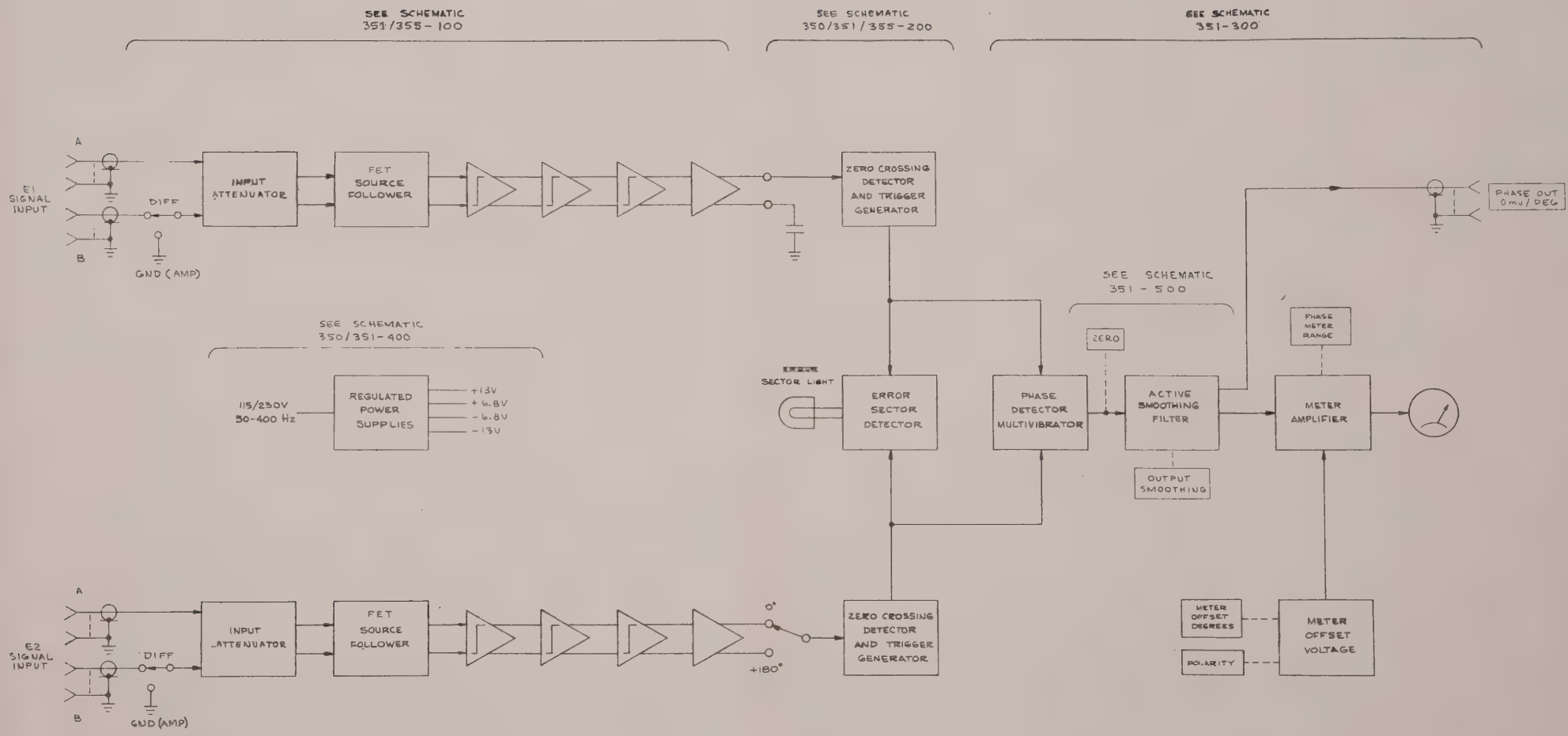


Figure 4-1. Graph of Phase Angle vs. Output Voltage of Phase Detector



WILTRON MODEL 351 BLOCK DIAGRAM

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WILTRON MODEL 351 BLOCK DIAGRAM

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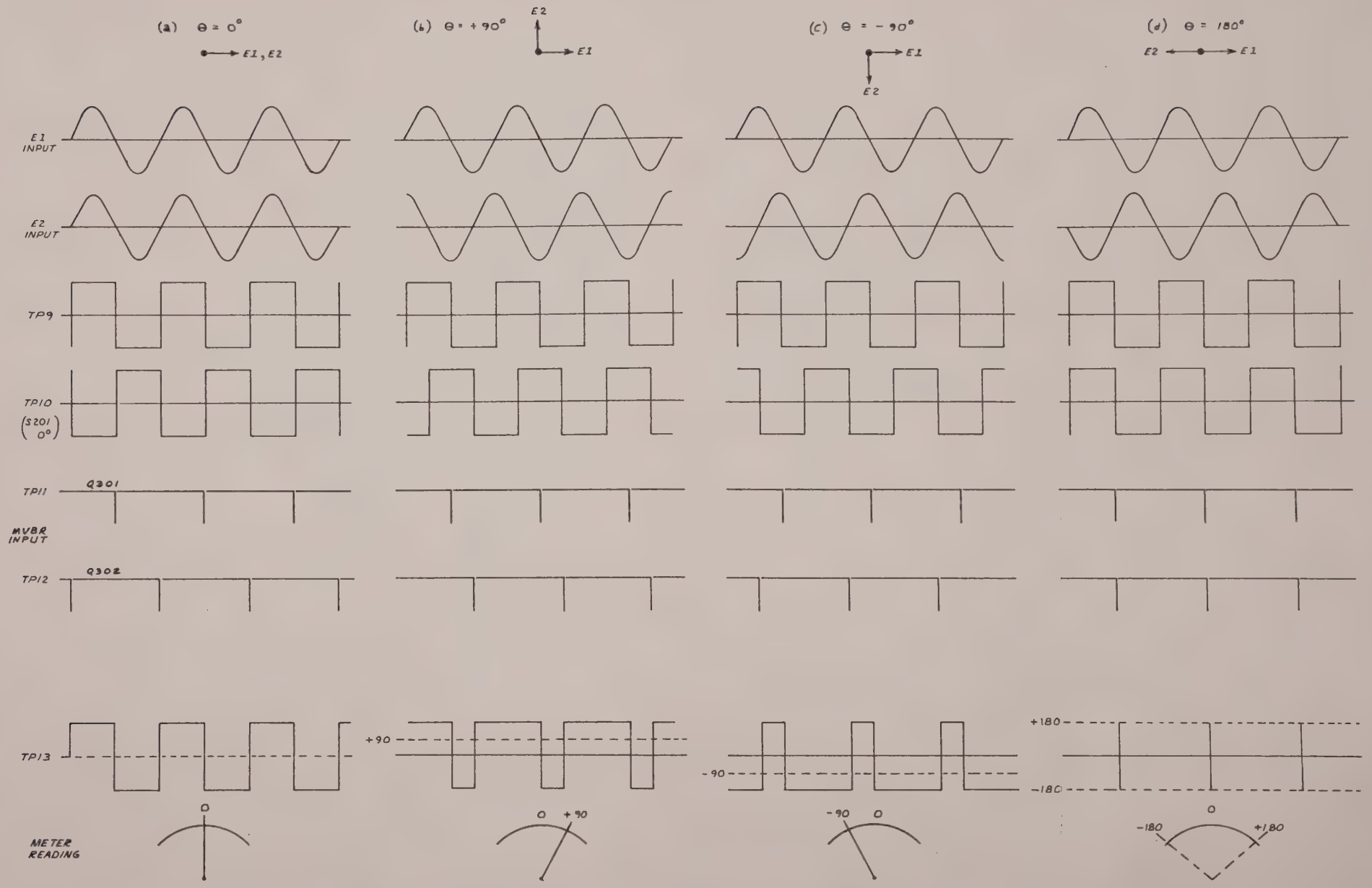

FIG. 4-3

WAVE FORMS AT FOUR PHASE ANGLES

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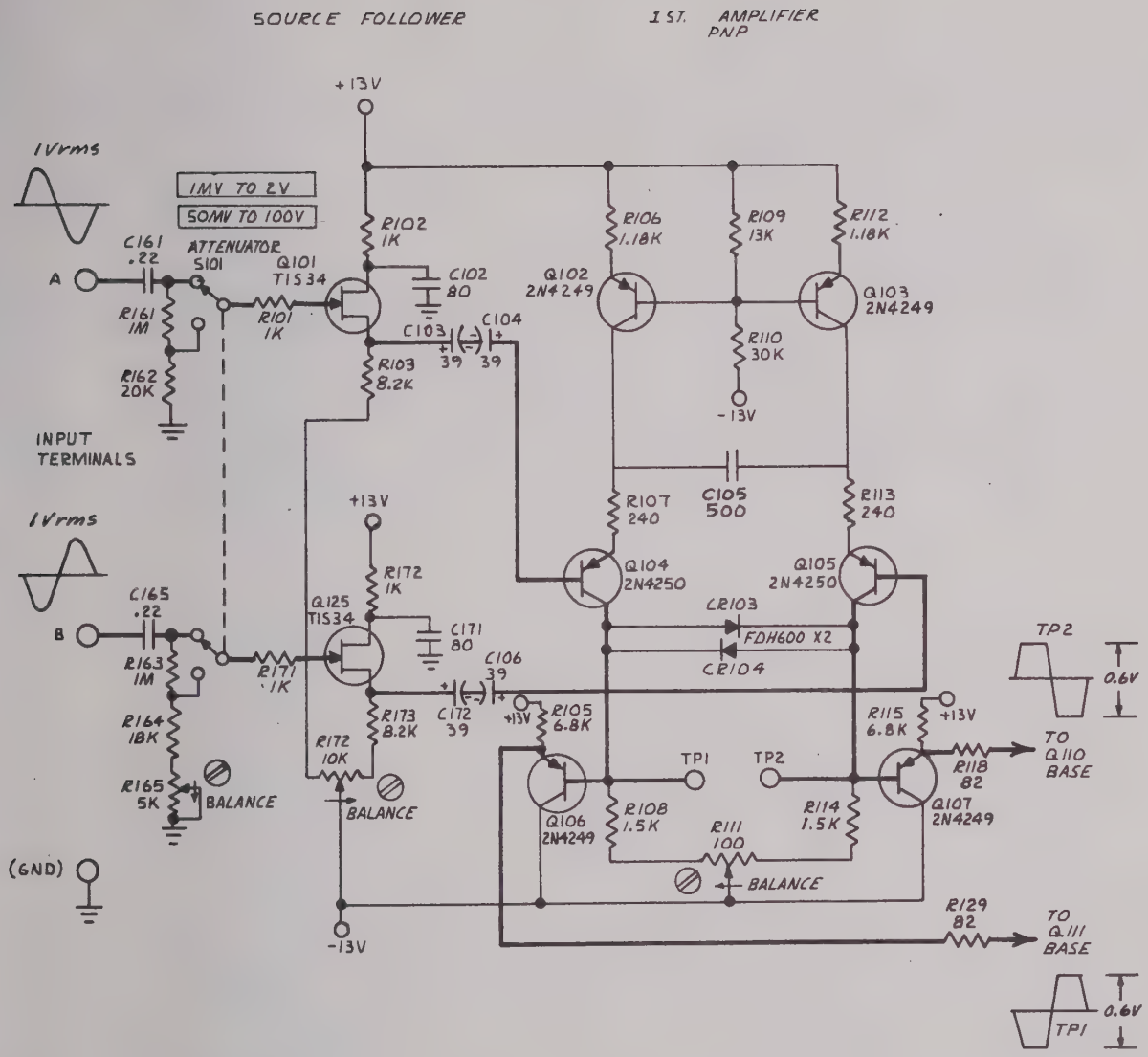


FIG. 4-4

SOURCE FOLLOWER AND FIRST AMPLIFIER

SIMPLIFIED SCHEMATIC DIAGRAM

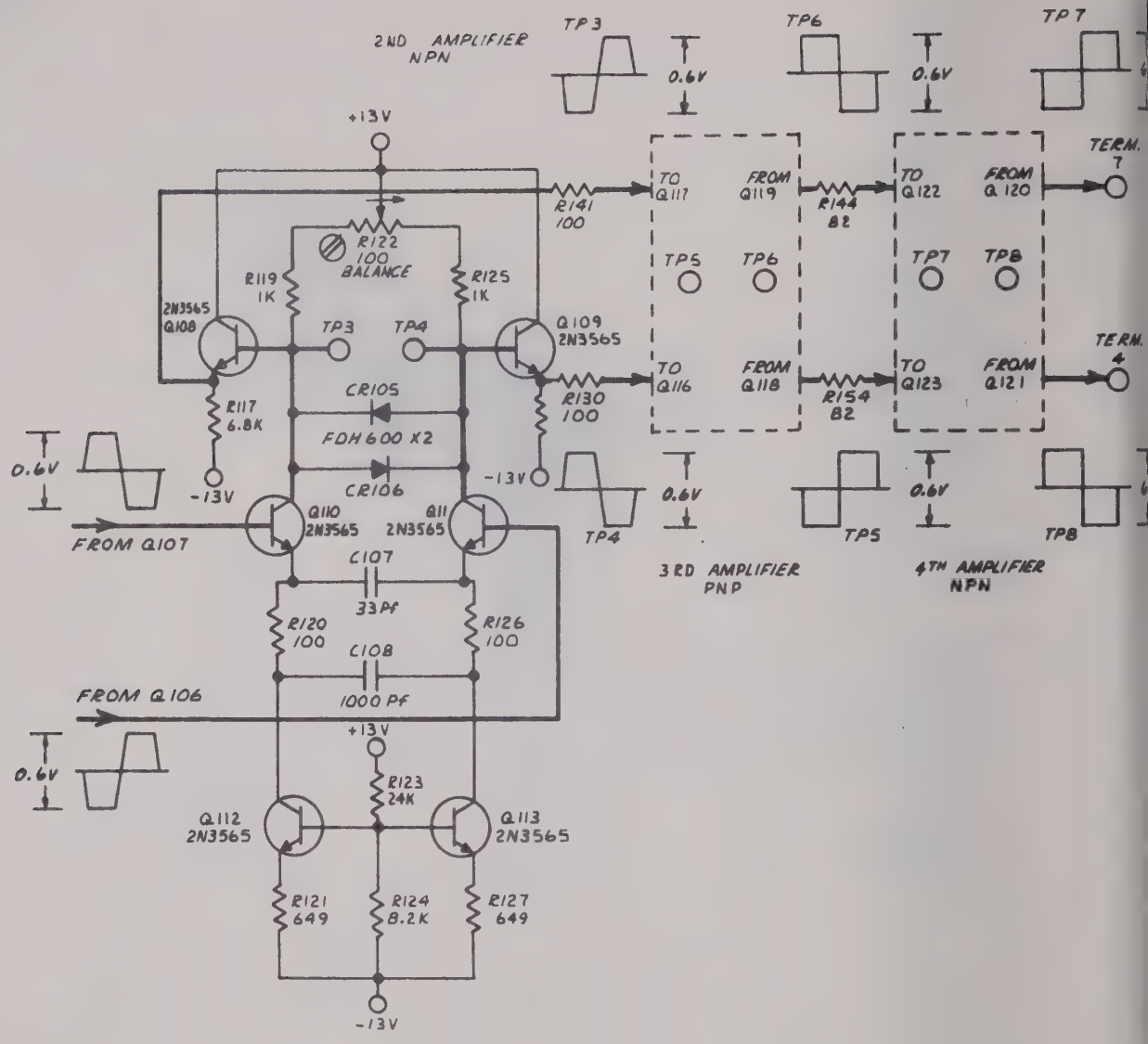


FIG. 4-5

SECOND, THIRD AND FOURTH SIGNAL AMPLIFIERS SIMPLIFIED SCHEMATIC DIAGRAM

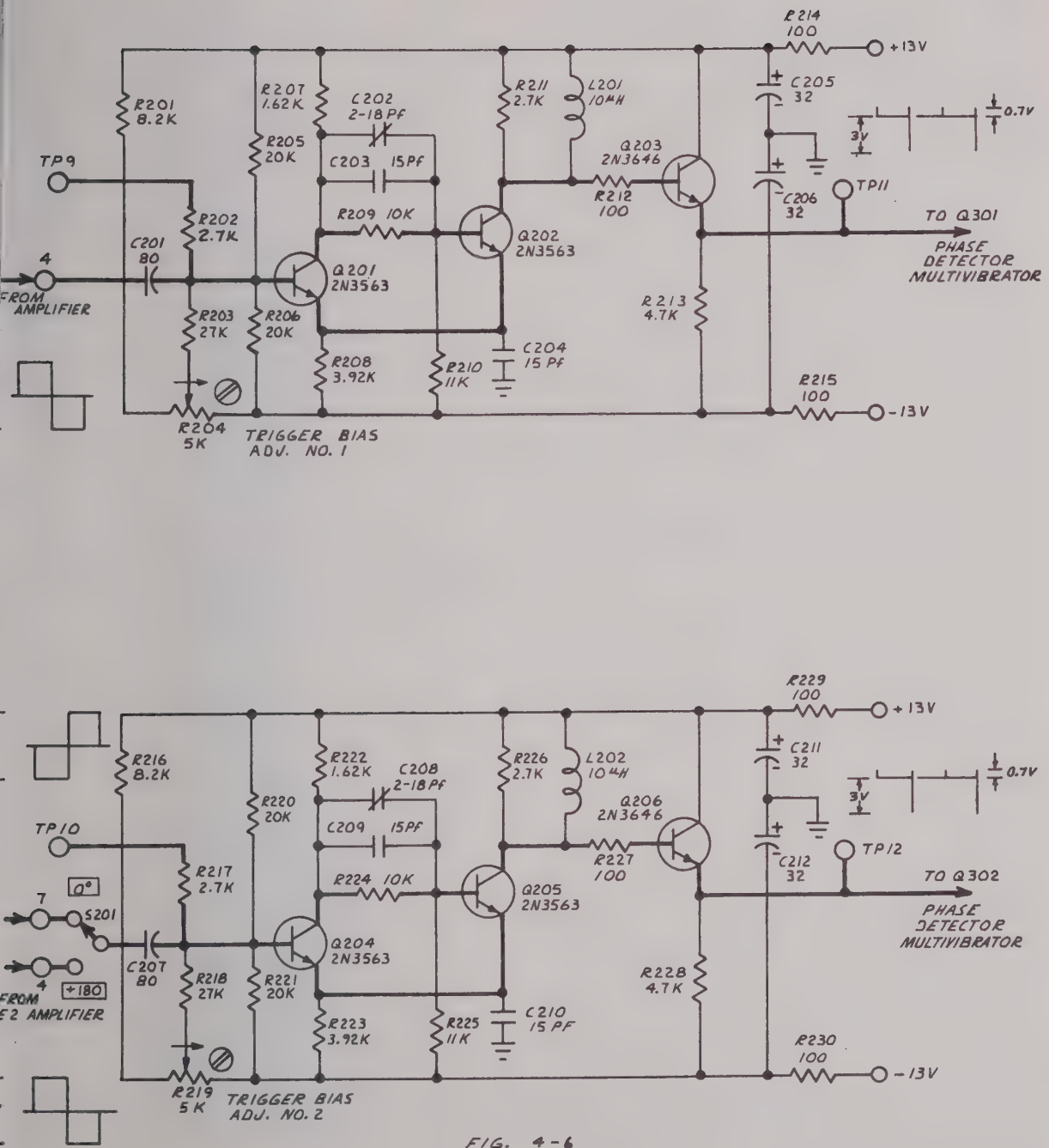


FIG. 4-6
TRIGGER CIRCUIT
SIMPLIFIED SCHEMATIC DIAGRAM

4-3. SOURCE FOLLOWER AND FIRST AMPLIFIER (Figure 4-4.)

Terminals A, B, and GND represent the input terminals for either E1 or E2. Follower and amplifier circuits are shown for only one signal amplifier board, the other being identical. S101 selects amplitude of input signal to be applied to gates of source follower FET's Q101 and Q125. Follower outputs are applied to the first balanced amplifier Q104 and Q105, a PNP stage. Q102 and Q103 are current regulators; Q106 and Q107 emitter followers feeding the output signal to the next stage. Test Points TP1 and TP2 allow oscilloscope checks of output signals applied to Q111 and Q110 respectively.

4-4. SECOND, THIRD AND FOURTH SIGNAL AMPLIFIERS (Figure 4-5)

Q110 and Q111 comprise the second balanced amplifier, an NPN stage. Alternate PNP and NPN stages are used in the amplifier to permit direct coupling. Q112 and Q113 are current regulators; Q108 and Q109 output emitter followers. TP3 and TP4 check output waveforms of this stage.

The third amplifier Q116 and Q117 is the same as the first amplifier, and the fourth, Q122 and Q123, the same as the second, except that the fourth has no limiter diodes in the collector circuit. TP7 and TP8 check output waveforms of the fourth stage, which should be steep-slope square waves for any amplitude of input signal within the rated input range. The output square wave in phase with A input is brought to numbered terminal 4 on the amplifier board; the one in phase with B input to numbered terminal 7.

4-5. TRIGGER CIRCUITS (Figure 4-6)

Note that the E1 trigger circuit uses input from the Ep amplifier board terminal 4 only, the non-inverting phase same as A. The E2 trigger circuit uses input from the E2 amplifier board terminal 7, the inverting phase same as B, with S201 in the 0° position. With the switch in the +180° position, it uses the non-inverting phase A from terminal 4 on the E2 amplifier board. The effect of using the 0° +180° switch is thus to shift the phase of the E2 trigger input only by 180°.

Q201-Q202 (E1 channel) and Q204-Q205 (E2 channel) are Schmitt trigger circuits which switch between two bistable states with very fast switching times when their input voltage varies only slightly (about half a volt) above and below a preset level. Trigger bias adjustments R204 and R219 set the dc bias of the input circuits to equal the lower trigger level of the Schmitt circuits. Thus the ac coupled signals from the E1 and E2 amplifiers swing the trigger circuit inputs equally above and below this level.

Considering the E1 trigger circuit (the E2 circuit description being the same) as the signal crosses the lower trigger level in the negative-going direction, Q201 is turned off and Q202 is turned on. The negative step developed across R211 is differentiated into a narrow pulse by L201 and delivered by the emitter follower Q203 to the phase detector multivibrator. The Schmitt trigger is reset when the signal crosses the upper trigger level, Q201 is turned on and Q202 turned off. The base collector junction of Q203 acts as a clamp to prevent the formation of a positive tail on the output pulses. Input signals to the Schmitt triggers can be observed at TP9 and TP10; output pulses at TP11 and TP12.

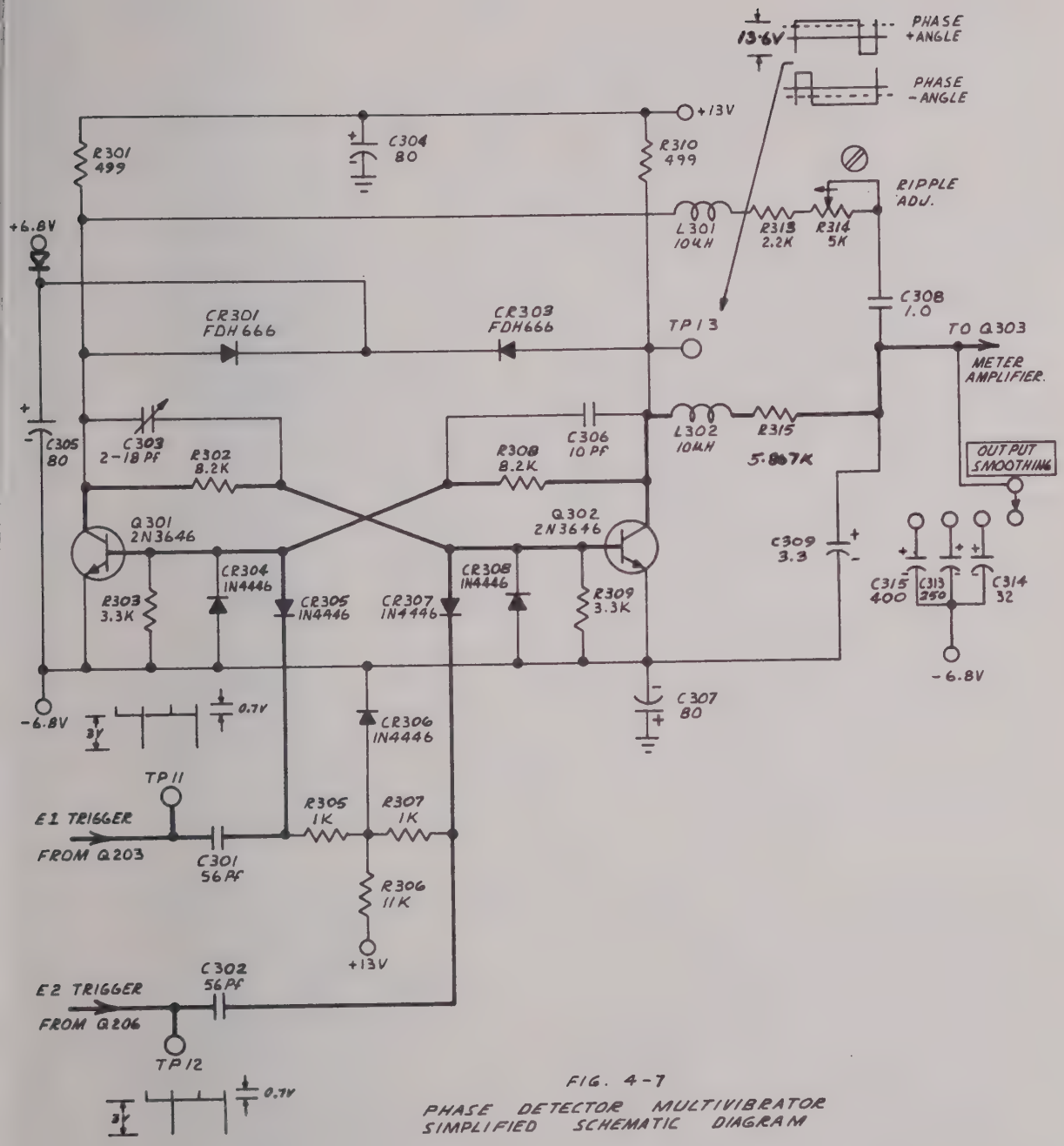


FIG. 4-7
PHASE DETECTOR MULTIVIBRATOR
SIMPLIFIED SCHEMATIC DIAGRAM

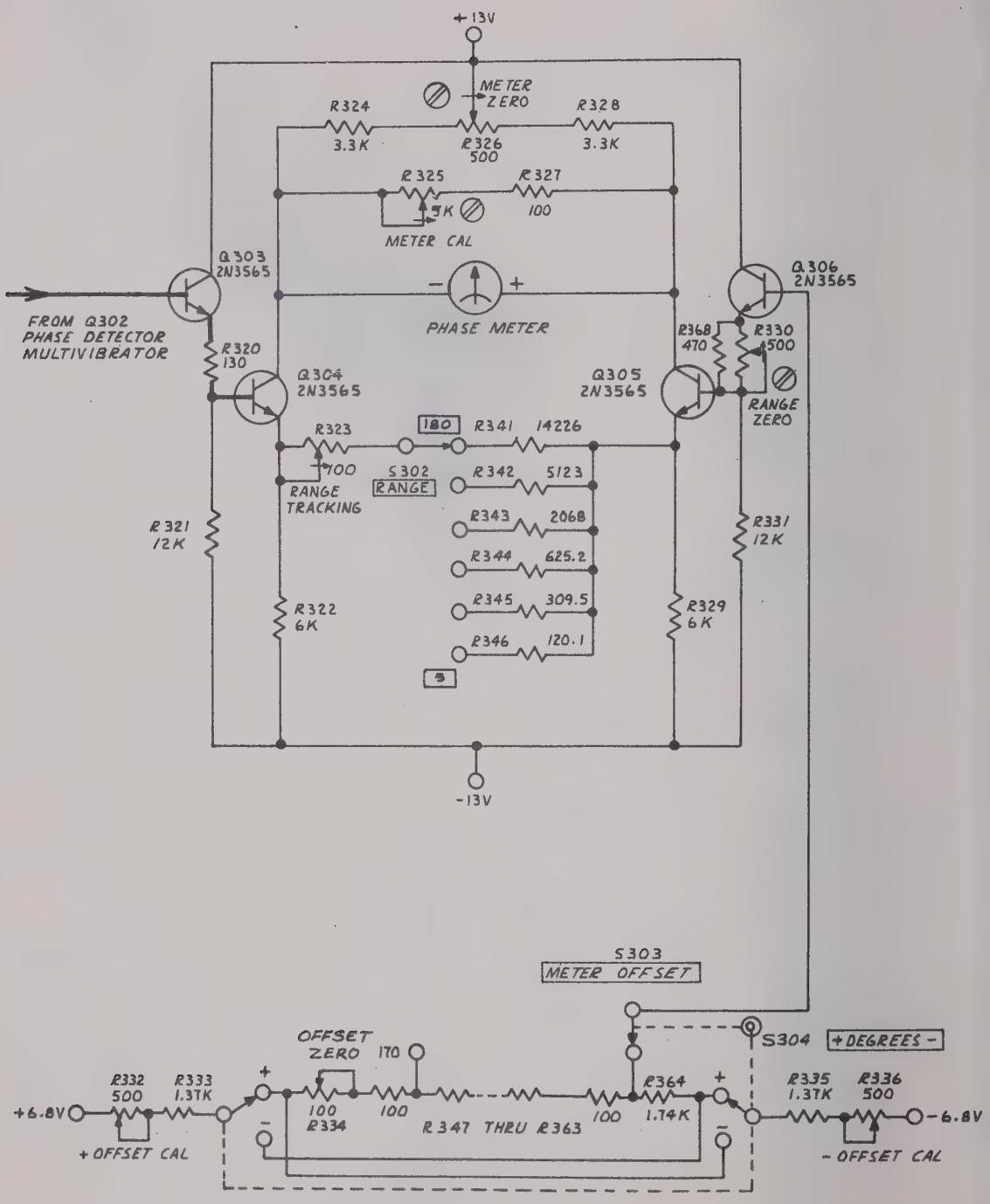


FIG. 4-8

METER AMPLIFIERS AND OFFSET CIRCUIT
SIMPLIFIED SCHEMATIC DIAGRAM

4-6. PHASE DETECTOR MULTIVIBRATOR (Figure 4-7.)

Negative input pulses from the E1 and E2 trigger circuits are coupled to Q301 and Q302 respectively. The output of the symmetrical triggered multivibrator Q301 - Q302 is taken from the collector of Q302 and indicated at TP13 E1 trigger pulses turn on Q302 and cause a negative output step. E2 trigger pulses turn of Q302 and cause a positive output step. The relative phase difference between the E1 and E2 pulses determines duration of the positive and negative steps and the resultant amplitude and direction of dc component in the output. When the E1 and E2 pulses are displaced by 180° the output wave becomes a square wave with a zero dc component. When the input pulses are in phase the multivibrator is unstable, the error sector light comes on, and the 0° + 180° switch is used to displace the input pulses by 180°.

Output smoothing of the dc component in the output of Q302 in three steps is accomplished by switching in successively greater values of capacitance as low-pass filters. C314 and C315 in series form the first step, C313 and C315 in series the second step, and C315 alone the third.

4-7. METER AMPLIFIERS AND OFFSET CIRCUIT (Figure 4-8.)

The dc component of the phase multivibrator output is applied to one input of a balanced dc differential amplifier consisting of two Darlington pairs Q303-Q304 and Q305-Q306. Output voltage from a voltage divider across the 6.8 volt regulated dc supply is applied to the other amplifier input. Polarity of the offset voltage is selected by S305 which switches the polarity across the voltage divider. Amount of offset is selected by an 18-point switch S303 connecting to equal resistance taps on the voltage divider. Phase Meter Range is selected by a 6-position switch S302 which changes sensitivity of the meter amplifier by inserting different values of precision resistance between emitters of Q304 and Q305.

The meter amplifiers form a dc bridge which is balanced and yields a zero meter reading when there is no dc input component applied to Q303 and S303 is set at the zero degrees offset position. A positive dc voltage at Q303 increases current in Q304, decreases current in Q305, increases voltage at the + terminal of the meter and causes the meter to read positive due to current flow from right to left. Advancing the offset switch S303 will then increase the positive voltage to Q306 and tend to return the meter reading to zero. By offsetting as close as possible to zero and then switching to the most sensitive meter range, the phase reading can be obtained with high accuracy as the algebraic sum of the offset and the meter reading. For a negative input to Q303, S304 would first be switched to the - position, then the same offset procedure as shown above would apply.

4-8. ERROR SECTOR LIGHT (Schematic 351-200).

The function of this circuit is to energize lamp DS201 whenever the output pulses from the E1 and E2 Schmitt trigger circuits become nearly coincident, the condition for phase angles approaching 180°. E1 pulses from Q203 and E2 pulses from Q206 are applied to an "AND" circuit consisting of the diode network and circuit of CR201-4. Providing that none of the area of an E2 pulse coincides with an E1 pulse, the output pulses at the emitter of Q207 are too small in amplitude to trigger the one-shot multivibrator Q208-Q209. Under these conditions Q209 is off, and Q210 is off keeping the light out.

4-8. ERROR SECTOR LIGHT (Cont.)

At some phase angle near 180° a portion of the E2 pulse will coincide with the E1 pulse. Regardless of the width of the portion coinciding, a pulse will result at the emitter of Q207 and be capacitively coupled through diode CR208 to Q209, cutting off Q209 and turning on Q208. The time constant of C218 amd R241 will maintain this condition for 25 milliseconds, during which time Q210 is on and the lamp is lighted before resetting. For input frequencies above about 40 Hz the lamp will be lighted continuously, and at lower frequencies its light will appear continuous down to about 24 Hz where flicker will start to become noticeable. When the lamp is lighted it signals the need to shift the E2 signal 180° by changing the position of the 0° + 180° switch. This action moves the E2 pulses to 180° out of phase with the E1 pulses, extinguishing the lamp and transferring the meter reading to zero.

If the 0 - 180° switch is operated when the meter reading is near zero, the Error Sector Light may or may not come on. As discussed, this circuit senses when phase angles near to 180° are present, the waveforms must be within 0.2μ sec of each other for the circuit to operate. The front panel zero control does not affect whether the light is on or not because it is not a phase shifing control.

4-9. POWER SUPPLY AND REGULATORS.

The power supply can be considered in two parts. The first part is a 26 volt regulated supply and the second part is an electronic voltage splitter that divides the 26 volts evenly into plus and minus 13 volts, reference to ground.

The unique part of the 26 volts regulated supply is that the 5.9 volt reference is used to control a current source Q405. The constant current through R441 creates a constant voltage that is referenced to the plus 13 volt buss. It is used as a reference voltage for one transistor of a differential amplifier Q403 and Q404.

The voltage splitter compares the voltage from a voltage divider R415 and R416 to ground in a differential amplifier. The output from the differential amplifier is amplified in Q408. Q409 and Q410 can not both be on at the same time because the base emitter junction of one is reversed biased while the junction in the other is forward biased. Q409 shunts current to ground from the + 13 volt buss and Q410 shunts current from the - 13 volt buss. Therefore current can be shunted from one side of the power supply or the other side to make loading equal for both sides and the output from the 26 volt regulated supply is split in two parts to become the + 13V and - 13V supplies.

The 5.9 volt reference voltage is voltage divided from the across zener diode CR411. The upper portion of the voltage divider contains R424. Either one, both or neither may be shorted at terminals 33, 34 and 35 as a means of obtaining an accurate 5.9 volt supply.

SECTION V
MAINTENANCE

5-1. INTRODUCTION

This section contains information required to maintain optimum performance of the phase meter and to locate and repair malfunctions. The section is divided into five major subject areas as follows: Test Equipment Required, Preventive Maintenance, Performance Verification, Calibration and Troubleshooting.

5-2. TEST EQUIPMENT REQUIRED

Table 5-1 lists the test equipment required to perform the procedures in this section. Equipment with equivalent characteristics may be used if the specified items are not available. Common hand tools are not listed.

5-3. PREVENTIVE MAINTENANCE

The phase meter normally requires no servicing during operation. If, however, it is operated in an extreme environment, dust, for example, periodic cleaning should be performed according to standard laboratory practices.

WARNING: Hazardous voltages are present with the covers removed. Always disconnect ac power at the source before cleaning.

Table 5-1. Test Equipment Required

COMMON NAME	MFG. MODEL OR TYPE NO.	CHARACTERISTICS
Oscilloscope with 10 to 1 Probe	Tektronix Model 543 with Type 'L' Plug-in	
Digital or Differential Voltmeter	Fluke Model 871	$\gg$ 10 Megohm Input Impedance
Audio Oscillator	Hewlett-Packard 651 B	10 Hz to 2 MHz
Attenuators (2)	Hewlett-Packard 355D	10 dB calibrated steps
Resistive Splitter	Wiltron 3211	50 ohm, two way
50 ohm through terminations (2)	Tektronix 011-0049-00	
BNC Type Shorting Connector		
100k ohm Resistors, 2 ea.		1/4w, 1%
1.0 pF Capacitor		
3.3 pF Capacitor		

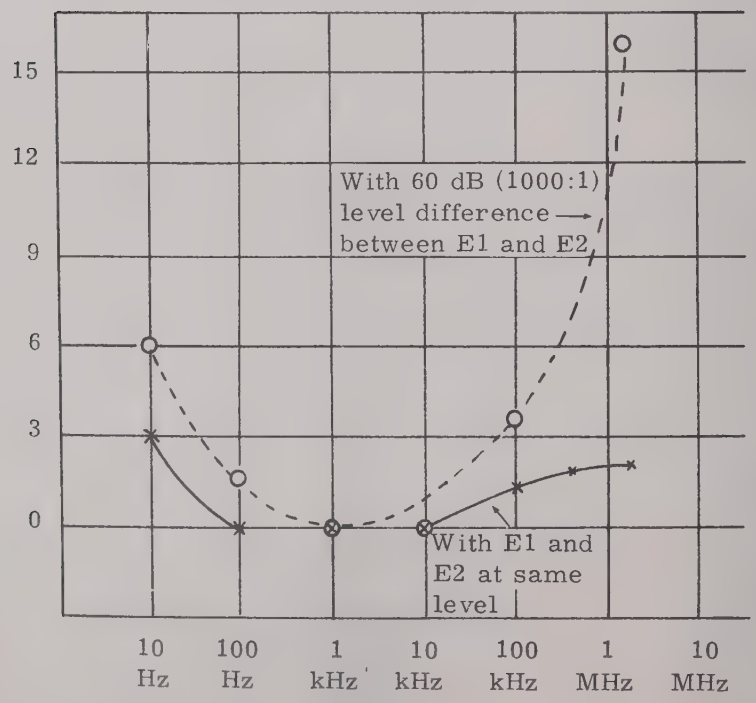
Table 5-2 Display Readout Zero Change
Due to Signal Level Variation

E1 Input	Degrees						
1v (200 v)	1.5	1.0	0.7	0.3	0.3	0.3	0.3
300 mv (60 v)	1.3	0.7	0.5	0.2	0.2	0.2	0.3
100 mv (20v)	1.0	0.7	0.4	0.2	0.2	0.2	0.3
30 mv 6 v	1.0	0.4	0.2	0	0.2	0.2	0.2
10 mv (2 v)	0.8	0.4	0.2	0.2	0.4	0.5	0.7
3 mv (600 mv)	0.5	0.2	0.2	0.2	0.4	0.7	1.0
1 mv (200 mv)	0.5	0.4	0.5	0.5	0.7	1.0	1.5
E2 Input	1 mv (200mv)	3 mv (600mv)	10 mv (2 v)	30 mv (6 v)	100mv (20 v)	300mv (60 v)	1 v (200 v)

NOTE

The E1 and E2 inputs are shown for both positions of the input attenuator switches. Input values in parentheses correspond to the low range 1 mv to 2 v position of the switches.

Table 5-3
Display Readout Zero Change
Due to Input Frequency Variations



4. PERFORMANCE VERIFICATION

he following steps are for checking the rformance of the Model 351 Phase eter. They should be conducted period-ally to assure top performance of the strument. Appropriate calibration sec-ons are referenced with each check. efer to the Calibration Section for the st of Test Equipment needed.

5. READOUT ZEROS

1. With the instrument turned off, note the meter reading using the ±5° scale. If the reading exceeds .05° from zero, readjust the mechanical zero of the meter using a small screwdriver through the panel access hole.

2. Power the instrument and allow a 15 minute warmup. Connect test equipment as shown in Test Set Up A and set the panel controls as indicated.

3. Adjust panel ZERO control to read exactly zero with METER RANGE on ±5. Vary METER RANGE through all positions and note the change in indication on panel meter. Pointer should move less than 0.1° as read on ±5° scale. See Section 5-15 for adjustment.

4. Connect the DVM to PHASE OUT terminal and adjust panel ZERO control for 0 ± 1 mv on this voltmeter. Set METER RANGE to ±5°. Meter should indicate 0° ± 0.2°. See Section 5-15 for adjustment.

5. Set the frequency of the test oscillator to 10 Hz and the METER RANGE switch to ±5°. Note the large flutter to the meter pointer. Advance the LOW FREQ. LIMIT control progressively through its positions and note the progressive reduction in pointer flutter. This check should locate any faulty contact or smoothing capacitor. Return the control to the 1000 Hz position and return Test Oscillator to 1 kHz. Note that the meter time constant becomes shorter as the switch is rotated from the 10 Hz position toward the 1000 Hz position.

5-6. METER AND OFFSET CALIBRATION.

1. Connect test equipment as shown in Test Setup A. Set the METER RANGE switch to ±10° and set to zero using panel ZERO control. Set in +10° with METER OFFSET control. Meter should read -10°. Change METER OFFSET to -10°. Meter should read +10°. Using appropriate settings, check each range of the METER RANGE switch.

2. THE METER OFFSET is accurate within ±0.5% of its indicated magnitude and the meter should indicate within 2% of its full face arc. See Section 5-15 for adjustments.

3. The ±5° RANGE may be checked by using METER OFFSET of 0° and adjusting the panel ZERO control for a 5.0° reading. Set METER RANGE to +10° and check for a 5° ±.2° indication. See Section 5-15 for adjustments.

5-7. PHASE CALIBRATION

1. With test equipment as shown in Test Setup A, connect the DVM to the PHASE OUTPUT connector. Insure that the model 351 has had at least 15 minutes of warmup.

2. Set front panel controls to Standard Control Settings (see Section 5-12.) Use panel ZERO control to obtain a

5-7. PHASE CALIBRATION (Cont.)

0.0000 reading on DVM. Remove signal input to E2 and replace with a short. Use a very short length of buss wire to prevent the possibility of a long lead acting as a loop antenna. The DVM should indicate -1.8000 volts ±5.4 mv ± the DVM accuracy.

If occasional jumps in the reading are noted, the precautions relating to shielding input leads and eliminating ground loops as described in Section 3-3 should be followed. In extremely noisy environments, calibration confirmation can still be accomplished by connecting a .0001μf or .01μf disc ceramic (high frequency) capacitor across the input terminals.

3. Replace the signal to E2 and similarly apply the short to E1. The DVM should indicate +1.8000 volts ±5.4 mv ± the DVM accuracy. See Section 5-14 for adjustments.

5-8. LEVEL VARIATIONS

1. With the test equipment as shown in Test Setup B, with 1 kHz test frequency set the METER RANGE switch to ±5°. Adjust the panel ZERO control for a zero reading on the panel meter.

2. Reduce the setting of both 1 and 2 attenuators together in 10 dB steps and note the phase reading. If in covering the range 0 to 60 dB the phase readout changes greater than 1° for a 20 dB level change in both inputs, refer to Section 5-16 for adjustments.

5-9. FREQUENCY VARIATION

1. With the test equipment as shown in Test Setup A, set the METER RANGE switch to ±5° and the input switches to the 200 mv to 400 v position. Set the input level to 30 mv rms on each channel at 1 kHz. Adjust the ZERO control for zero reading on the meter. Increase the test frequency to 1 MHz in steps, then to 2 MHz. Note phase readings. Reduce the test frequency to 100 Hz, switch the Low Frequency Limit control to 100 Hz position. Note the phase reading. Make a similar measurement at 10 Hz with the LOW FREQ LIMIT switch in the 10 Hz position. The phase zero should change less than ±1° from 100 Hz to 100 kHz and less than ±4° from 10 Hz to 2 MHz.

See Section 5-16 for corrective action if these readings are exceeded.

5-10. PHASE ACCURACY CHECK

1. The preceding procedure adequately covers the phase performance of the instrument. The following confidence check is included because of its simplicity and the ready availability of the necessary components. Users having precision phase generators may use them for phase check.

2. Use Test Setup B as modified by Connection 1 shown in Figure 5-1. Set the Test Oscillator to 1 kHz, attenuator No. 1 to 30 dB, and attenuator No. 2 to 20 dB. Note the 50 ohm resistor across the cable providing the E2 signal. Set the panel ZERO control for a panel meter reading of zero degrees using the ±5° range. If more accurate readings are desired, use a precision high impedance voltmeter on the PHASE OUT connector and set it to zero rather than the panel meter.

3. Change from Connection 1 to Connection 2 using the component values indicated and short lead length to mini-

-10. PHASE ACCURACY CHECK (Cont)

mize pickup of extraneous signals. Precision values are not required, but the component quality should be good, ie., use a capacitor with Mylar or similar low loss dielectric so that is parallel shunt leakage path is negligible. Record the phase reading with this connection.

4. Change to Connection 3 and record the phase reading. The sum of the two phase readings should be 90° ±0.47 ± voltmeter tolerance when read at PHASE OUT connector or an additional ±0.8° is considered when using the OFFSET and 10° METER RANGE for readout.

5. If the tolerances of this phase check are not met, conduct the preceding checks of the Performance Verification Test to determine the nature of the fault and the appropriate recalibration section.

-11. CALIBRATION PROCEDURE

The following paragraphs contain a procedure in seven parts for recalibrating the phase meter. Under normal circumstances, regularly scheduled recalibration of the phase meter will not be required. However, if the performance verification tests indicate a need for calibration, or if any of the phase meter circuit boards are replaced or repaired, the appropriate parts of the procedure should be performed.

-12. STANDARD CONTROL SETTINGS

Unless otherwise stated, the standard position of front panel controls during calibration is shown in Table 5-4.

NOTE: See Figure 5-3 for location of test points and adjustments.

Table 5-4. Standard Control Settings

CONTROL	POSITION
INPUT MODE switch	GND (Amp)
INPUT ATTENUATORS	1 mv to 2v
PHASE METER RANGE switch	180°
LOW FREQ LIMIT control	1000 Hz
METER OFFSET	0°, +

5-13. POWER SUPPLIES

1. +5.8v reference. Set the voltage on pin 35 to +5.8v ±20 mv by placing a resistor or jumper across pins 35, 36, 37 (any combination) to increase the voltage to +5.8; or increase the value of R424 to decrease the voltage to +5.8v.

   NOTE: The +5.8 v reference may have been adjusted above or below the nominal value to optimize the -1.8000 v adjustment range. Perform the remaining power supply checks and Section 5-14 before changing the +5.8 v reference.

2. Measure the 26 volt supply across terminals 38 and 39 with an off-ground DVM. Voltage should be 26 volts ±0.2 v. If out-of-tolerance, adjust R412 for this voltage. Otherwise leave it unchanged.

3. Ripple on ±13 v lines: Vary the supply voltage from 102 to 125 volts rms and measure the ac ripple on C406 and C407, using an oscilloscope. It should be less than 2 mv p-p.

5-14. PHASE OUT VOLTAGE CALIBRATION.

1. With front panel controls in standard positions (see turn-on), using short clip leads, connect terminals 23 and 28 on PC board number 2 to ground.

5-14. PHASE OUT VOLTAGE CALIBRATION (Cont.)

2. Measure voltage on the slider of R337 front panel ZERO control and adjust to 0 ±1 mv.

3. Remove the ground connection from terminal 28.

4. Short the E2 - A input and apply a 1 volt rms signal at 1 kHz to the E1 - A input.

5. Measure the voltage on the PHASE OUT connector. The reading should be -1.800 v ±1 mv. If necessary, set to -1.800 using R441 -180° PHASE ADJ control

6. Transfer the short to the E1 - A input, and apply the 1 kHz signal to E2 - A input.

7. The PHASE OUT voltage should now be +1.8000 v ±1 mv. If necessary set to +1.800 v using R434 +180° PHASE ADJ control.

5-15. OFFSET AND METER CALIBRATION.

A. OFFSET CONTROL

1. Measure voltage on terminal 16 on board 2. The reading should be +3.4 v ±10 mv. If necessary set to +3.400 v ±1 mv using R332 OFFSET CAL.

2. Measure voltage on terminal 19 on board 2 with OFFSET polarity switch in the - position. Switch to + . The measured voltage should be within 2 mv of - position. If not, set voltage to ±.1 mv of previously measured voltage using R334 OFFSET ZERO control.

3. Repeat steps 1 and 2 as required.

4. Remove ground from terminal 23. Check voltage on terminal 23 to be 0 ±10 mv. If not, set to 0 ±1mv using R336 OFFSET CAL control.

B. METER ZERO

1. Short the meter terminals and adjust mechanical zero. Remove short.

2. Set phase out to 0 ±1 mv with front panel ZERO control Use fluke DVM.

3. Meter should read zero. If not, adjust R326 METER ZERO to give zero meter reading.

4. Turn METER RANGE switch to 5° range. Meter should read zero. If necessary adjust R330 RANGE ZERO control on rear panel.

5. Repeat steps 3 and 4 as necessary, returning RANGE SWITCH to 180° range.

C. METER CAL.

1. Connect a 1 volt rms 1 kHz signal to E1 - A input. Short E2 - A input. The meter should read - 180°. Note this reading.

2. Connect the test signal to E2 - A input. Short E1 - A input. The meter should read +180°. Note this reading.

3. Adjust METER CAL R325, if necessary, to minimize METER symmetry error.

4. Connect terminal 28 on board 2 to ground.

5. Set RANGE switch to 10° position. Be sure meter reads 0 (RANGE ZERO R330).

5-15. OFFSET AND METER CAL (Cont.)

6. Set in 10° offset. Switching polarity + to -, adjust RANGE TRACKING R323 to minimize meter error.

7. Use the METER OFFSET control to check the meter accuracy in +10° steps on each position of the METER RANGE switch. Switch the OFFSET polarity to negative and check each position of the METER RANGE switch.

5-16. AMPLIFIER CIRCUIT ADJUSTMENTS.

1. Disconnect the oscillator and the voltmeter from the phase meter. Connect BNC type shorting connectors to the E1 - A and E2 A input connectors.

   Set the digital voltmeter for differential operation. Connect the voltmeter between test points TP1 and TP2 on the E1 amplifier circuit card 351-1 via two 100 K ohm resistors (one on each lead). The voltmeter reading should be 0 V (±1 mv). If not, adjust R111 on the E1 amplifier circuit card to obtain the correct value.

2. Connect the voltmeter between test points TP3 and TP4 via the 100 K ohm resistors. Connect a shorting jumper between test points TP1 and TP2. The voltmeter reading should be 0 V (±1 mv), If not, adjust R122 to obtain the correct value.

3. Connect the voltmeter between test points TP5 and TP6 via the 100 K ohm resistor. Transfer the shorting jumper from TP1 - TP2 to TP3 - TP4. The voltmeter reading should be 0 V (±1 mv), If not, adjust R137 to obtain the correct reading.

4. Connect the voltmeter between test point TP7 and TP8 via the 100K ohm resistors. Transfer the shorting jumper to TP5 - TP6. The voltmeter reading should be 0 V (±10 mv). If not, adjust R150 to obtain the correct value.

5. Repeat the procedure using the corresponding test points and adjustments on the E2 amplifier circuit card. (Balance controls R165 and R174 are not adjusted at this time and should not be touched.)

5-17. TRIGGER CIRCUIT ADJUSTMENTS

A. OVERSHOOT ADJUST

1. Apply a 600 kHz 1 volt rms signal to E1 - A and E2 A inputs. Connect an oscilloscope via a 1 pf capacitor and a 10 to 1 compensated probe to TP9. Adjust C111 for equal positive and negative overshoot on the leading and trailing edge of the square wave.

2. Repeat this procedure on the E2 amplifier using TP10 and C111 on E2 amplifier board.

B. TRIGGER BIAS ADJUST.

1. With a 1 kHz test signal applied to E1 - A and E2 - A inputs, attenuate each 30 dB and adjust panel ZERO for zero meter reading in 5° range.

2. Attenuate E1 60 dB and if necessary adjust R204 TRIGGER BIAS ADJ No. 1 to bring meter back to zero. Vary attenuator in 10 dB steps from 0 to 60 dB, noting that the average meter reading varies less than 0.2° from 0 to 40 dB and less than 0.4° from 40 to 60 dB.

3. Repeat step 2 on E2 amplifier, making adjustment with R219 TRIGGER BIAS ADJ No. 2.

5-17. TRIGGER CIRCUIT ADJUSTMENTS (Cont).

C. RISE/FALL TIME ADJUSTMENTS

1. With 600 kHz at 1 volt rms (at 0 dB attenuation) input on each amplifier, connect the oscilloscope via a 3.3 pf capacitor and 10 to 1 compensated probe to TP13. Set sweeptime at .1 μsec, sweep magnified x 20. Adjust C303 for equal rise and fall time between 10% and 90 % levels.

   NOTE: You may have to compromise the 10% and 90% levels and the zero crossing point to equalize truly. Check that in varying both the attenuators at the same time from 30 to 0 dB the meter does not change more than 1.5° from zero.

5-18. ATTENUATOR COMPENSATION

A. E1 ATTENUATOR

1. Apply 1 volt rms to E1 and E2 inputs at 100 kHz. Attenuate E1 and E2 40 dB. Zero the meter on the 5° range with the panel control. Switch the E1 attenuator to the 200 mv to 400 v position. Remove the 40 dB attenuation in E1. Adjust C162 to bring meter back to zero. Return switch to the 1 mv to 2 v position.

2. Transfer the ground from input "B" to "A" on E1. Apply the test signal to B input. Switch 0 - 180° switch to +180° zero meter with front panel zero control. Repeat the previous test adjusting C166 to bring meter back to zero.

B. E2 ATTENUATOR

1. Make similar checks on the E2 attenuator as on E1. Use the corresponding C162 and C166 trimmers on E2.

5-19. COMMON MODE REJECTION

A. E1: 1 mv - 2 v

1. Apply a 1 volt rms 1 kHz signal to E1 - A input. Ground B input. Attenuate E1 70 dB. Connect an oscilloscope via a 10 to 1 probe to TP9.

2. Note the amplitude of the signal on TP9. This is a reference. Remove the ground from B input. Connect the test signal to both A and B inputs.

3. Reduce the attenuator setting 50 dB. Adjust R174 for a null in output at TP9. Check that this signal is smaller than the reference amplitude.

4. Repeat steps 1 and 2 at 500 kHz.

5. Reduce the attenuator setting 40 dB. Adjust C173 or C174 for a null in output at TP9. Check that this signal is smaller than the reference amplitude.

B. E1: 200 mv - 400 v

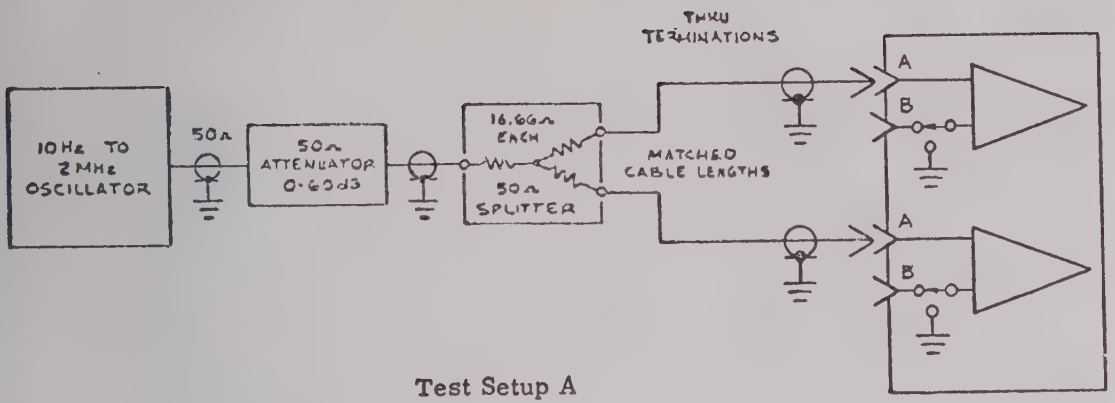
1. Apply a 3 volt rms 100 Hz signal to E1 - A input. Ground B input. Attenuate E1 50 dB.

2. Note the amplitude of the signal on TP9. This is a reference. Remove the ground from B input. Connect the test signal to both A and B inputs.

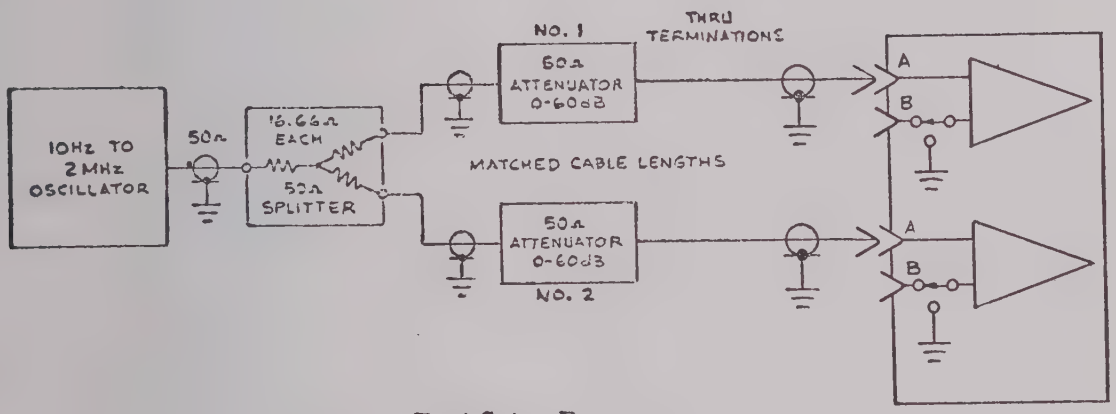
3. Reduce the attenuator setting 50 dB. Adjust R165 for a null in output at TP9. Check that this is smaller than the reference amplitude.

4. Repeat steps 1 and 2 at 300 kHz.

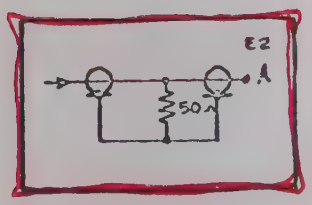
5. Reduce the attenuator setting 40 dB. Adjust C166 for a null in output at



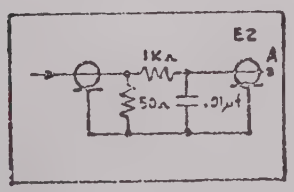
Test Setup A



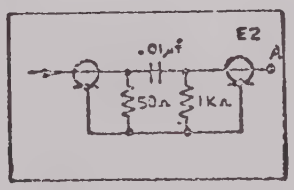
Test Setup B



Connection 1



Connection 2



Connection 3

NOTE: In test setups A and B, 75Ω or 600Ω components can be used with equal accuracy. If terminations are not used, the high frequency accuracy (500 kHz) may suffer.

Figure 5-1. Test Setups for Performance Verification and Recalibration Procedures.

5-19. COMMON MODE REJECTION (Cont)

TP9. Check that this signal is smaller than the reference amplitude.

C. E2: 1 mv - 2 v

1. Repeat A, 1 - 5 on E2 with corresponding attenuator and measurements made on TP10.

D. E2: 200 mv - 400 v

1. Repeat B, 1 - 5 on E2 with corresponding attenuator and measurements made on TP10.

5-20. AMPLIFIER COMPENSATION

With 1 kHz at 1 volt rms to attenuators set in 30 dB attenuation, zero meter on ±5° scale using zero control. Change input frequency to 2 MHz. The meter should read 0 ±.5° on 5° range. If necessary, use a small capacitor between TP1 and TP2 on E2 (or E1, depending on which side of zero the meter reads) to bring meter reading to zero. Typical values would be in the range of .68 - 3.3 pf.

5-21. TROUBLESHOOTING

When a malfunction is noted in operation of the phase meter, the operator should first perform the installation and operation procedures in Sections 2 and 3 to discover any obvious faults. The performance verification and recalibration procedures can then be used to attempt to isolate the malfunction to a particular circuit. The exact cause of the malfunction can next be located by circuit analysis and conventional test methods such as signal tracing, voltage and resistance measurements, and compon ent substitutions.

When troubleshooting, refer to the schematic diagrams in Section 7, the principles of operation discussion and simplified schematic diagrams in Section 4.. Use the performance verification guides. Be familiar with the operating precautions and other information in Section 3 to avoid problems which appear to be in the phase meter but actually are external faults associated with signal interference or improper test equipment interconnections.

Useful test voltages and waveforms are shown on the schematic diagrams in Section 6 and the simplified schematic diagrams in Section 4. Although these waveforms are typical and idealized, observation of the waveform at the test points will indicate whether or not the signal circuits up to that point are functioning or not.

5-22. CIRCUIT BOARD LOCATION AND ARRANGEMENT

The main sections of the instrument are the two identical signal amplifier boards (input boards), the board containing the trigger generators, phase detector multivitrator, error sector detector and meter amplifiers (output board), and the power supply. Figure 5-3 shows these sub-assemblies as viewed from the underside of the cabinet.

5-23. TROUBLESHOOTING PROCEDURE

The two basic types of trouble which can be encountered with this instrument are non-operation and apparent error. Locating and correcting non-operation is relatively straightforward. Careful observation of the effect should enable the isolation of the cause to a particular section or location. Troubleshooting for apparent error is likely to involve making adjustments and require going through a part or all of a recalibration procedure.

24. NON-OPERATION

n-operation troubles divide essentially o those involving lack of power and bse involving failure to process signals. the unit fails to turn on, check the fol- wing in sequence. (See Figure 2-2.)

1. Input power source.
2. Fuse.
3. Voltage Switch Selector S402
4. AC voltage at primary and secondary of power transformer T401.

the unit turns on but appears completely operative, check the dc output voltages terminals 2 and 5 on the power supply assis.

25. TEST VOLTAGES AND WAVEFORMS.

eful test voltages are shown on the hematic drawings. Waveform amplides are shown on the simplified schetic drawings. (See pages 4-7 thru 4-12.)

26. SIGNAL TRACING

oubleshooting failure of the unit to pross signals is best accomplished by applying a common input signal to the E1 and E2 inputs and then tracing them through the signal paths by the oscilloscope observation at each test point. The simplified schematic diagrams in Section 4 are well suited for waveform comparison. Waveforms observed in this manner, although not ideal in shape like the qualitive sketches on the simplified schematics, will be close enough to indicate whether the signal cirucits up to the observed point are or are not functioning. A fault in one channel can be diagnosed by waveform and voltage comparisons with the good channel.

5-27. METER AMPLIFIER CIRCUIT

Trouble in the meter amplifiers can be quickly isolated by making a check of the voltage at the PHASE OUT terminals with input wignal applied. If the PHASE OUT voltage is normal and the meter does not read or does not agree, the trouble is in the meter amplifier section.

5-28. JUMPY READINGS

Jumpy readings are usually caused by ac power line noise getting into the test setup. See Section 3-3, PRECAUTIONS TO TAKE FOR STABLE PHASE ANGLE MEASUREMENTS.

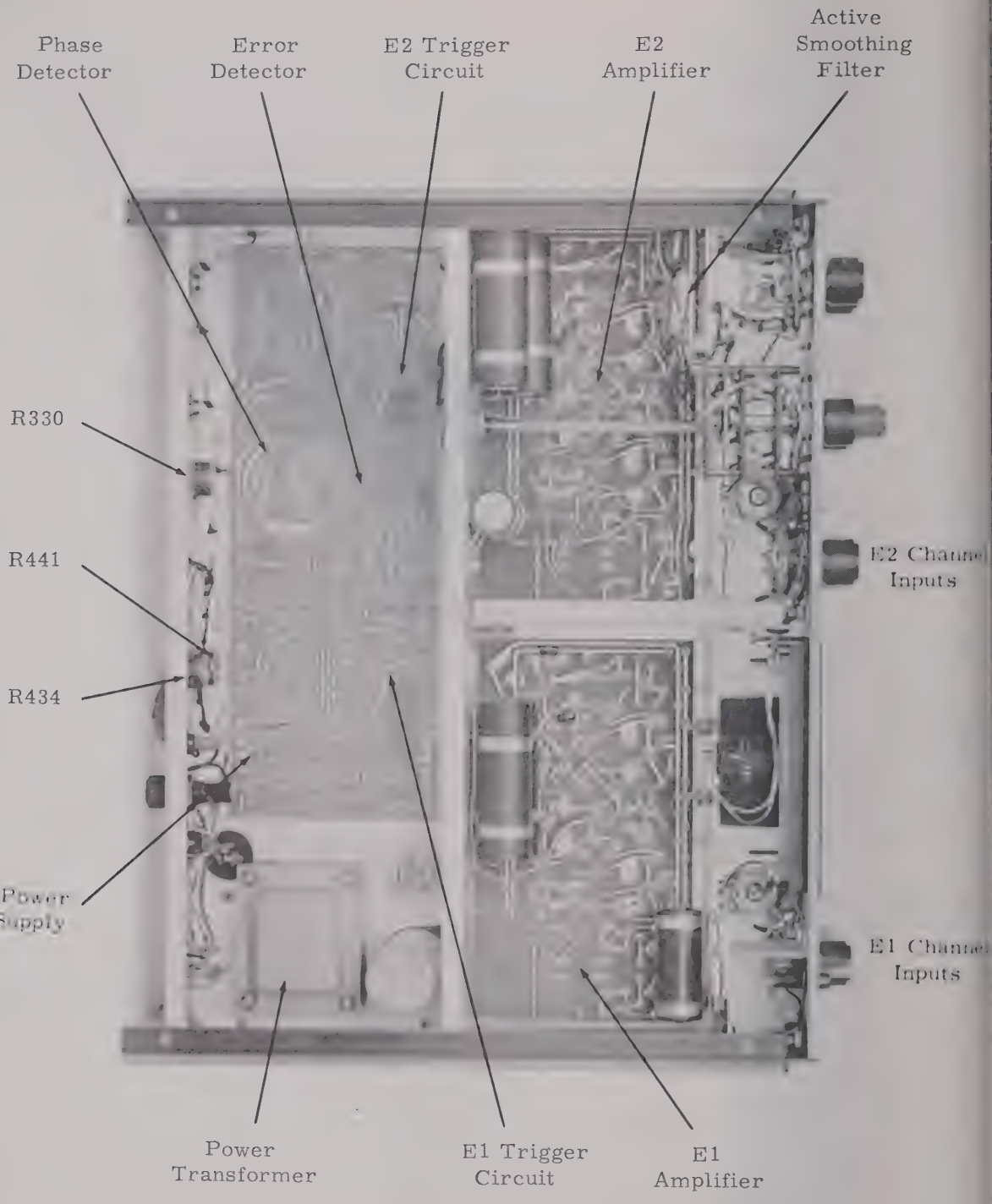


Figure 5-2

Top Interior View

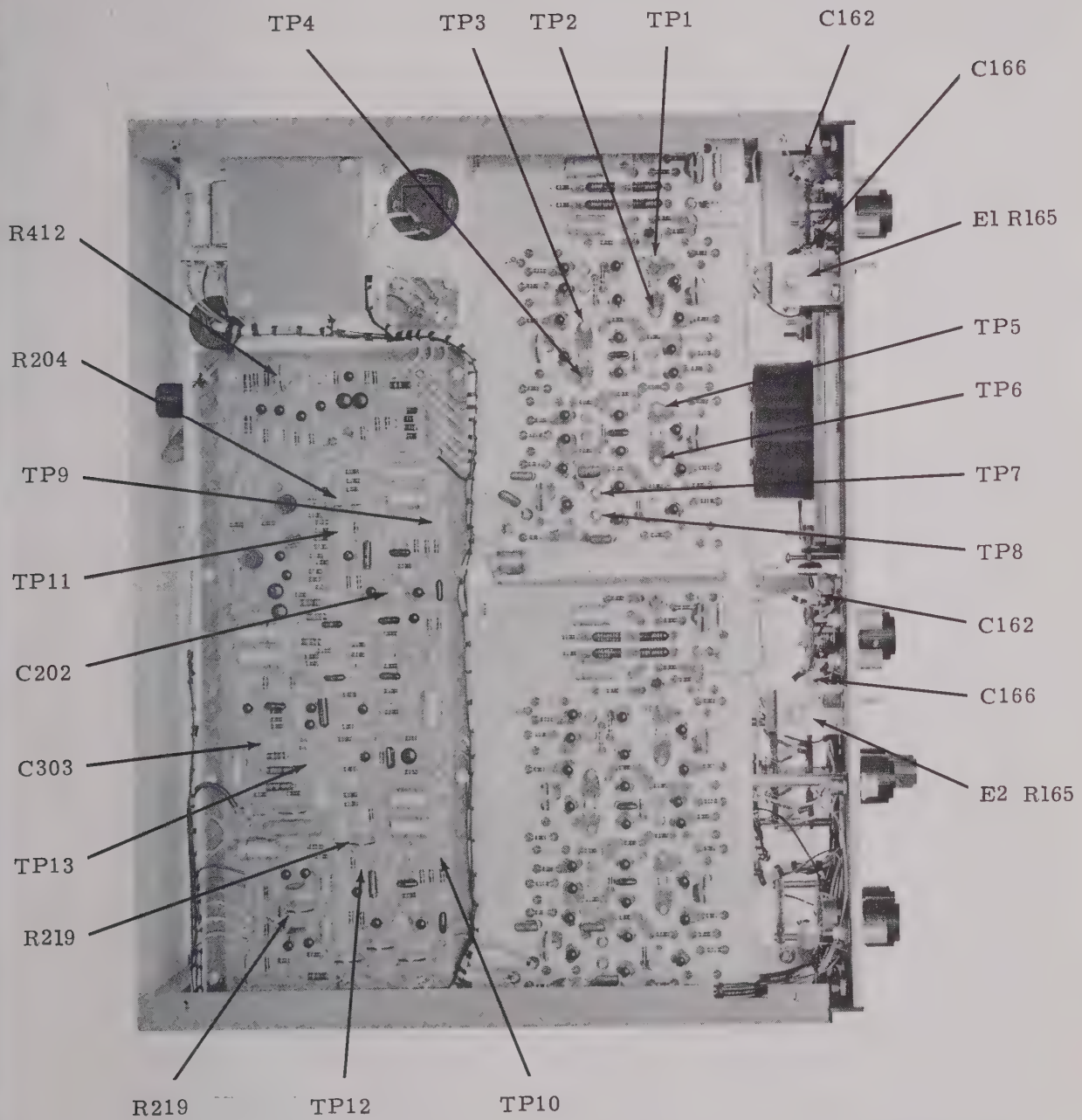


Figure 5-3

Bottom Interior View

SECTION VI

MODEL 351 PARTS LIST

Resistors

101	1K	1/4W	5%	Fixed Comp
102	1K	1/4W	5%	Fixed Comp
103	8.2K	1/4W	5%	Fixed Comp
104	20K	1/4W	5%	Fixed Comp
105	6.8K	1/4W	5%	Fixed Comp
106	1.18K	1/4W	1%	Fixed Film
107	240	1/4W	5%	Fixed Comp
108	1.5K	1/4W	1%	Fixed Film
109	13K	1/4W	5%	Fixed Comp
110	30K	1/4W	5%	Fixed Comp
111	100	.2W	20%	Var Comp
112	1.18K	1/4W	1%	Fixed Comp
113	240	1/4W	5%	Fixed Comp
114	1.5K	1/4W	1%	Fixed Film
115	6.8K	1/4W	5%	Fixed Comp
116	20K	1/4W	5%	Fixed Comp
117	6.8K	1/4W	5%	Fixed Comp
118	82	1/4W	5%	Fixed Comp
119	1K	1/4W	1%	Fixed Film
120	100	1/4W	5%	Fixed Comp
121	649	1/4W	1%	Fixed Film
122	100	.2W	20%	Var Comp
123	24K	1/4W	5%	Fixed Comp
124	8.2K	1/4W	5%	Fixed Comp
125	1K	1/4W	1%	Fixed Film
126	100	1/4W	5%	Fixed Comp
127	649	1/4W	1%	Fixed Film
128	6.8K	1/4W	5%	Fixed Comp
129	82	1/4W	5%	Fixed Comp
130	82	1/4W	5%	Fixed Comp
131	6.8K	1/4W	5%	Fixed Comp
132	649	1/4W	1%	Fixed Film
133	100	1/4W	5%	Fixed Comp
134	1K	1/4W	1%	Fixed Film
135	8.2K	1/4W	5%	Fixed Comp
136	24K	1/4W	5%	Fixed Comp
137	100	.2W	20%	Var Comp
138	649	1/4W	1%	Fixed Film
139	100	1/4W	5%	Fixed Comp
140	1K	1/4W	1%	Fixed Film

Resistors

R141	82	1/4W	5%	Fixed Comp
R142	6.8K	1/4W	5%	Fixed Comp
R143	3.9K	1/4W	5%	Fixed Comp
R144	82	1/4W	5%	Fixed Comp
R145	1K	1/4W	1%	Fixed Film
R146	100	1/4W	5%	Fixed Comp
R147	24K	1/4W	5%	Fixed Comp
R148	8.2K	1/4W	5%	Fixed Comp
R149	432	1/4W	1%	Fixed Film
R150	100	.2W	20%	Var Comp
R151	1K	1/4W	1%	Fixed Film
R152	100	1/4W	5%	Fixed Comp
R153	3.9K	1/4W	5%	Fixed Comp
R154	82	1/4W	5%	Fixed Comp
R161	1M	1/2W	1%	Fixed Film
R162	4.99	1/4W	1%	Fixed Film
R163	1M	1/2W	1%	Fixed Film
R164	4.75	1/4W	1%	Fixed Film
R165	500	1/2W	20%	Var Comp
R171	1K	1/4W	5%	Fixed Comp
R172	1K	1/4W	5%	Fixed Comp
R173	8.2K	1/4W	5%	Fixed Comp
R174	10K	.2W	20%	Var Comp
R201	8.2K	1/4W	5%	Fixed Comp
R202	2.7K	1/4W	5%	Fixed Comp
R203	27K	1/4W	5%	Fixed Comp
R204	5K	.2W	20%	Var Comp
R205	20K	1/4W	5%	Fixed Comp
R206	20K	1/4W	5%	Fixed Comp
R207	1.62K	1/8W	1%	Fixed Film
R208	3.92K	1/8W	1%	Fixed Film
R209	10K	1/8W	1%	Fixed Film
R210	11K	1/8W	1%	Fixed Film
R211	2.7K	1/4W	5%	Fixed Comp
R212	100	1/4W	5%	Fixed Comp
R213	4.7K	1/4W	5%	Fixed Comp
R214	100	1/4W	5%	Fixed Comp
R215	100	1/4W	5%	Fixed Comp
R216	8.2K	1/4W	5%	Fixed Comp
R217	2.7K	1/4W	5%	Fixed Comp
R218	27K	1/4W	5%	Fixed Comp

Resistors

R219	5K	.2W	20%	Var Comp	R314	5K	1/4W	20%	Var Comp
R220	20K	1/4W	5%	Fixed Comp	R315	5.867K	1/4W	0.1%	Fixed WW
R221	20K	1/4W	5%	Fixed Comp	R316	820	1/2W	5%	Fixed Comp
R222	1.62K	1/8W	1%	Fixed Film	R317	10K	1/4W	5%	Fixed Comp
R223	3.92	1/8W	1%	Fixed Film	R318	3.3	1/4W	0.1%	Fixed WW
R224	10K	1/8W	1%	Fixed Film	R320	130	1/4W	5%	Fixed Comp
R225	11K	1/8W	1%	Fixed Film	R321	12K	1/4W	5%	Fixed Comp
R226	2.7K	1/4W	5%	Fixed Comp	R322	6.00K	1/4W	0.1%	Fixed WW
R227	100	1/4W	5%	Fixed Comp	R323	100	.2W	20%	Var Comp
R228	4.7K	1/4W	5%	Fixed Comp	R324	3.3K	1/4W	5%	Fixed Comp
R229	100	1/4W	5%	Fixed Comp	R325	5K	.2W	20%	Var Comp
R230	100	1/4W	5%	Fixed Comp	R326	500	.2W	20%	Var Comp
R231	10K	1/4W	5%	Fixed Comp	R327	100	1/4W	5%	Fixed Comp
R232	10K	1/4W	5%	Fixed Comp	R328	3.3K	1/4W	5%	Fixed Comp
R233	2.2K	1/4W	5%	Fixed Comp	R329	6.00K	1/4W	0.1%	Fixed WW
R234	2.2K	1/4W	5%	Fixed Comp	R330	500	2W	10%	Var Cermet
R235	47K	1/4W	5%	Fixed Comp	R331	12K	1/4W	5%	Fixed Comp
R236	3.3K	1/4W	5%	Fixed Comp	R332	500	.2W	20%	Var Comp
R237	10K	1/4W	5%	Fixed Comp	R333	1.37K	1/8W	1%	Fixed Film
R238	2.7K	1/4W	5%	Fixed Comp	R334	100	.2W	20%	Var Comp
R239	4.7K	1/4W	5%	Fixed Comp	R335	1.37K	1/8W	1%	Fixed Film
R240	10K	1/4W	5%	Fixed Comp	R336	500	.2W	20%	Var Comp
R241	47K	1/4W	5%	Fixed Comp	R337	500K	1/2W	20%	Var Comp
R242	47K	1/4W	5%	Fixed Comp	R338	110K	1/4W	5%	Fixed Comp
R243	10K	1/4W	5%	Fixed Comp	R341	14226	1/4W	0.1%	Fixed WW
R244	4.7K	1/4W	5%	Fixed Comp	R342	5123	1/4W	0.1%	Fixed WW
R245	10K	1/4W	5%	Fixed Comp	R343	2068	1/4W	0.1%	Fixed WW
R301	499	1/2W	1%	Fixed Film	R344	625.2	1/4W	0.1%	Fixed WW
R302	8.2K	1/4W	5%	Fixed Comp	R345	309.5	1/4W	0.1%	Fixed WW
R303	3.3K	1/4W	5%	Fixed Comp	R346	120.1	1/4W	0.1%	Fixed WW
R304	130	1/2W	5%	Fixed Comp	R347	100 matched set		1%	Fixed Film
R305	1K	1/4W	5%	Fixed Comp	R348	100 matched set		1%	Fixed Film
R306	11K	1/4W	5%	Fixed Comp	R349	100 matched set		1%	Fixed Film
R307	1K	1/4W	5%	Fixed Comp	R350	100 matched set		1%	Fixed Film
R308	8.2K	1/4W	5%	Fixed Comp	R351	100 matched set		1%	Fixed Film
R309	3.3K	1/4W	5%	Fixed Comp	R352	100 matched set		1%	Fixed Film
R310	499	1/2W	1%	Fixed Film	R353	100 matched set		1%	Fixed Film
R311	330	1/2W	5%	Fixed Comp	R354	100 matched set		1%	Fixed Film
R312	8.2K	1/4W	5%	Fixed Comp	R355	100 matched set		1%	Fixed Film
R313	2.2K	1/4W	5%	Fixed Comp	R356	100 matched set		1%	Fixed Film

sistors

57	100 matched set	1%		Fixed Film
58	100 matched set	1%		Fixed Film
59	100 matched set	1%		Fixed Film
60	100 matched set	1%		Fixed Film
61	100 matched set	1%		Fixed Film
62	100 matched set	1%		Fixed Film
63	100 matched set	1%		Fixed Film
64	1.74K 1/8W	1%		Fixed Film
65	470 1/4W	5%		Fixed Comp
01	1.0 3W	5%		Fixed WW
02	5.6K 1/4W	5%		Fixed Comp
03	3.6K 1/4W	5%		Fixed Comp
04	1.0 1/2W	5%		Fixed Comp
05	10 1/4W	5%		Fixed Comp
06	6.8K 1/4W	5%		Fixed Comp
07	20K 1/4 W	5%		Fixed Comp
08	3.01K 1/8W	1%		Fixed Film
09	12.70K 1/8W	1%		Fixed Film
10	24K 1/4W	5%		Fixed Comp
11	2.00K 1/8W	1%		Fixed Film
12	250 .2W	20%		Var Comp
13	2.21K 1/8W	1%		Fixed Film
14	62K 1/4W	5%		Fixed Comp
15	20.0K 1/8W	1%		Fixed Film
16	20.0K 1/8W	1%		Fixed Film
17	47K 1/4W	5%		Fixed Comp
18	240K 1/4W	5%		Fixed Comp
19	10K 1/4W	5%		Fixed Comp
20	7.5K 1/4W	5%		Fixed Comp
21	1K 1/4W	5%		Fixed Comp
22	430 1/2W	5%		Fixed Comp
23	430 12/W	5%		Fixed Comp
24	28.7 1/8W	1%		Fixed Film
25	56.2 1/8W	1%		Fixed Film
26	866 1/8W	1%		Fixed Film
27	464 1/8W	1%		Fixed Film
28	1.3K 1/4W	5%		Fixed Comp
29	100K 1/4W	5%		Fixed Comp
30	91K 1/4W	5%		Fixed Comp
31	100K 1/4W	5%		Fixed Comp

Resistors

R432	200	1/4W	5%	Fixed Comp
R433	1K	1/8W	1%	Fixed Film
R434	500	2W	10%	Var Cermet
R435	9.31K	1/8W	1%	Fixed Film
R436	100K	1/4W	5%	Fixed Comp
R437	1K	1/4W	5%	Fixed Comp
R438	12K	1/4W	5%	Fixed Comp
R439	130	1/2W	5%	Fixed Comp
R440	9.24K	1/4W	0.1%	Fixed WW
R441	500	2W	10%	Var Cermet
R442	11.12K	1/4W	0.1%	Fixed WW
R443	16K	1/4W	5%	Fixed Comp
R444	200	1/4W	5%	Fixed Comp
R445	30K	1/4W	5%	Fixed Comp
R446	16K	1/4W	5%	Fixed Comp
R447	5.1K	1/4W	5%	Fixed Comp
R448	330	1/4W	5%	Fixed Comp
R449	3.6K	1/4W	5%	Fixed Comp
R450	100	1/2W	5%	Fixed Comp
R451	3K	1/4W	5%	Fixed Comp
R452	6.6K	1/4W	0.1%	Fixed WW
R453	270K	1/4W	5%	Fixed Comp
R454	270K	1/4W	5%	Fixed Comp
R455	3.3K	1/4W	0.1%	Fixed WW
R456	820K	1/4W	5%	Fixed Comp
R457	270K	1/4W	5%	Fixed Comp
R458	22M	1/4W	5%	Fixed Comp
R459	22M	1/4W	5%	Fixed Comp
R460	1.5K	1/4W	5%	Fixed Comp
R461	22	1/4W	5%	Fixed Comp
R462	1K	1/4W	5%	Fixed Comp

Capacitors

C101	15μf	20V	10%	Fixed Tant
C102	80μf	25V		Fixed Lytic
C103	39μf	10V	20%	Fixed Tant
C104	39μf	10V	20%	Fixed Tant
C105	500μf	15V		Fixed Lytic

Capacitors

C106	39μf	10V	20%	Fixed Tant
C107	39ρf	500V	5%	Fixed Mica
C108	1000μf	15V		Fixed Lytic
C109	1000μf	15V		Fixed Lytic
C110	39ρf	500V	5%	Fixed Mica
C111	5-60ρf Amperex C1010MA/60E			
C112	.1μf	250V	20%	Fixed Mylar
C113	.1μf	250V	20%	Fixed Mylar
C114	20ρf	500V	5%	Fixed Mica
C115	15ρf	500V	5%	Fixed Mica
C161	.22μf*	400V	10%	Fixed Mylar
C162	1.2 - 10ρf Stettner-Trush 104-02-M			
C163	1300ρf	500V	5%	Fixed Mica
C164	10ρf*	500V	5%	Fixed Mica
C165	.22μf*	400V	10%	Fixed Mylar
C166	1.2 - 10ρf Stettner-Trush 104-02-M			
C167	1300ρf	500V	5%	Fixed Mica
C168	10ρf*	500V	5%	Fixed Mica
C171	80μf	25V		Fixed Lytic
C172	39μf	10V	20%	Fixed Tant
C173	*			
C174	*			
C175	1.0μf	35V	10%	Fixed Tant
C176	1.0μf	35V	10%	Fixed Tant
C201	80μf	25V		Fixed Lytic
C202	2-18ρf Amperex C010KA/20E			
C203	15ρf*	500V	5%	Fixed Mica
C204	15ρf	500V	5%	Fixed Mica
C205	32μf	64V		Fixed Lytic
C206	32μf	64V		Fixed Lytic
C207	80μf	25V		Fixed Lytic
C208	2-18ρf Amerpex C010KA/20E			
C209	15ρf*	500V	5%	Fixed Mica
C210	15ρf	500V	5%	Fixed Mica
C211	32μf	64V		Fixed Lytic
C212	32μf	64V		Fixed Lytic
C213	.047μf	250V	10%	Fixed Mylar
C214	.047μf	250V	10%	Fixed Mylar
C215	39ρf	500V	5%	Fixed Mica

Capacitors

C216	39ρf	500V	5%	Fixed Mica
C217	.047μf	250V	10%	Fixed Mylar
C218	.47μf	250V	20%	Fixed Mylar
C219	43ρf	500V	5%	Fixed Mica
C220	32μf	64V		Fixed Lytic
C301	56ρf	500V	5%	Fixed Mica
C302	56ρf	500V	5%	Fixed Mica
C303	2-18ρf Amperex C010KA/20E			
C304	80μf	25V		Fixed Lytic
C305	80μf	25V		Fixed Lytic
C306	10ρf	500V	5%	Fixed Mica
C307	80μf	25V		Fixed Lytic
C308	1.0μf	250V	10%	Fixed Mylar
C309	3.3μf	35V		Fixed Lytic
C310	.001μf	1KV	10%	Fixed Ceram
C311	.001μf	1KV	10%	Fixed Ceram
C312	.47μf	250V	20%	Fixed Mylar
C401	.02μf	500V	20%	Fixed Ceram
C402	.02μf	500V	20%	Fixed Ceram
C403	1000μf	50V		Fixed Lytic
C404	6.8μf	35V	10%	Fixed Tant
C405	4.7μf	10V	20%	Fixed Tant
C406	250μf	50V		Fixed Lytic
C407	250μf	50V		Fixed Lytic
C408	4.7μf	10V	20%	Fixed Tant
C409	.001μf	1KV	10%	Fixed Ceram
C410	4.7μf	10V	20%	Fixed Tant
C411	4.7μf	10V	20%	Fixed Tant
C412	4.7μf	10V	20%	Fixed Tant
C413	.001μf	1KV	10%	Fixed Ceram
C414	4.7μf	10V	20%	Fixed Tant
C415	0.15μf	100V	10%	Fixed Mylar
C416	0.47μf	250V	10%	Fixed Mylar
C417	0.47μf	250V	10%	Fixed Mylar
C418	1.0μf	250V	10%	Fixed Mylar
C419	0.22μf	250V	10%	Fixed Mylar
C420	0.47μf	250V	10%	Fixed Mylar
C421	0.1μf	250V	10%	Fixed Mylar
C422	1.0μf	250V	10%	Fixed Mylar
C423	1.0μf	250V	10%	Fixed Mylar

*Factory Selected Value

Capacitors

C424	.022μf 250V	10%	Fixed Mylar
C425	.068μf 100V	10%	Fixed Mylar
C426	0.22μf 250V	10%	Fixed Mylar
C427	.01μf 100V	20%	Fixed Ceram
C428	0.1μf 250V	10%	Fixed Mylar
C429	.0047μf 500V	10%	Fixed Mylar
C430	470pf 500V	5%	Fixed Mica

Transistors

Q102	2N4249	Q207	2N3646
Q103	2N4249	Q208	2N3646
Q104	2N4250	Q209	2N3646
Q105	2N4250	Q210	2N3566
Q106	2N4249	Q301	2N3646
Q107	2N4249	Q302	2N3646
Q108	2N3565	Q307	2N3646
Q109	2N3565	Q401	2N3055
Q110	2N3565	Q402	2N4249
Q111	2N3565	Q403	2N3566
Q112	2N3565	Q404	2N3566
Q113	2N3565	Q405	2N3565
Q114	2N4249	Q406	2N3565
Q115	2N4249	Q407	2N3565
Q116	2N4249	Q408	2N4249
Q117	2N4249	Q409	2N2218
Q118	2N4249	Q410	2N2905
Q119	2N4249	Q411	TD-100
Q120	2N3646	Q412	2N4249
Q121	2N3646	Q413	2N3566
Q122	2N3565	Q414	TD-100
Q123	2N3565	Q415	2N4249
Q124	2N3565	Q416	2N3566
Q201	2N3563	Q417	TD-100
		Q418	μA709
Q202	2N3563		
Q203	2N3646		
Q204	2N3563		
Q205	2N3563		
Q206	2N3646		

Capacitors

Q101, Q125 2N5248 matched pair for gm
WILTRON 351-S-975-A
Q303, Q306 2N3565 matched pair for Hfe
WILTRON 350-S-1206-A
Q304, Q305 2N3565 matched pair for Vbe
WILTRON 350-S-809-D

* Instrument may be equipped with 2N5086 instead of 2N4249

Diodes

CR101	1N4446	CR401	1N4383
CR102	1N4446	CR402	1N4383
CR171	1N4446	CR403	1N4383
CR172	1N4446	CR404	1N4383
CR201	1N4446	CR405	1N4446
CR202	1N4446	CR406	1N4446
CR203	1N4446	CR407	1N4446
CR204	1N4446	CR408	1N4446
CR205	1N4446	CR410	1N4446
CR206	1N4446	CR411	1N823
CR207	1N4446	CR412	1N4446
CR208	1N4446	CR413	1N4446
CR301	FDH666	CR414	1N3491R
CR302	FDH666	CR415	1N3491
CR303	FDH666		
CR304	1N4446		
CR305	1N4446		
CR306	1N4446		
CR307	1N4446		
CR308	1N4446		

CR103, CR104 FDH666 matched pair for voltage drop - WILTRON 350-S-808
CR105, CR106 FDH666 matched pair for voltage drop - WILTRON 350-S-808
CR107, CR108 FDH666 matched pair for voltage drop - WILTRON 350-S-808

Inductors

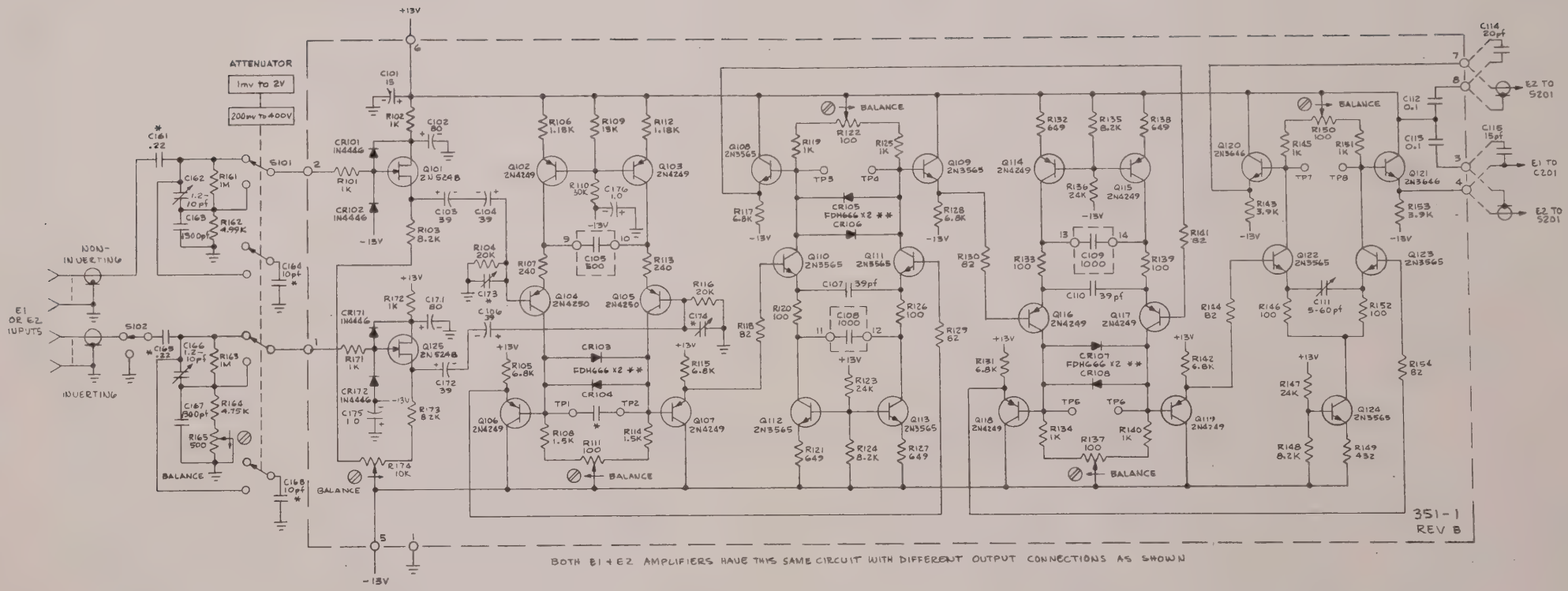
L201	100μhy	L301	10μhy
L202	100μhy	L302	10μhy

Switches

S101	Rotary	WILTRON 410-45
S102	SPDT	WILTRON 420-5
S201	Rotary	WILTRON 410-43
S301	Rotary	WILTRON 410-31
S302	Rotary	WILTRON 410-44
S303	Rotary part of	WILTRON 410-28
S304	Rotary part of	WILTRON 410-28
S401	SPST	WILTRON 420-1
S402	DPDT	WILTRON 430-9

Miscellaneous

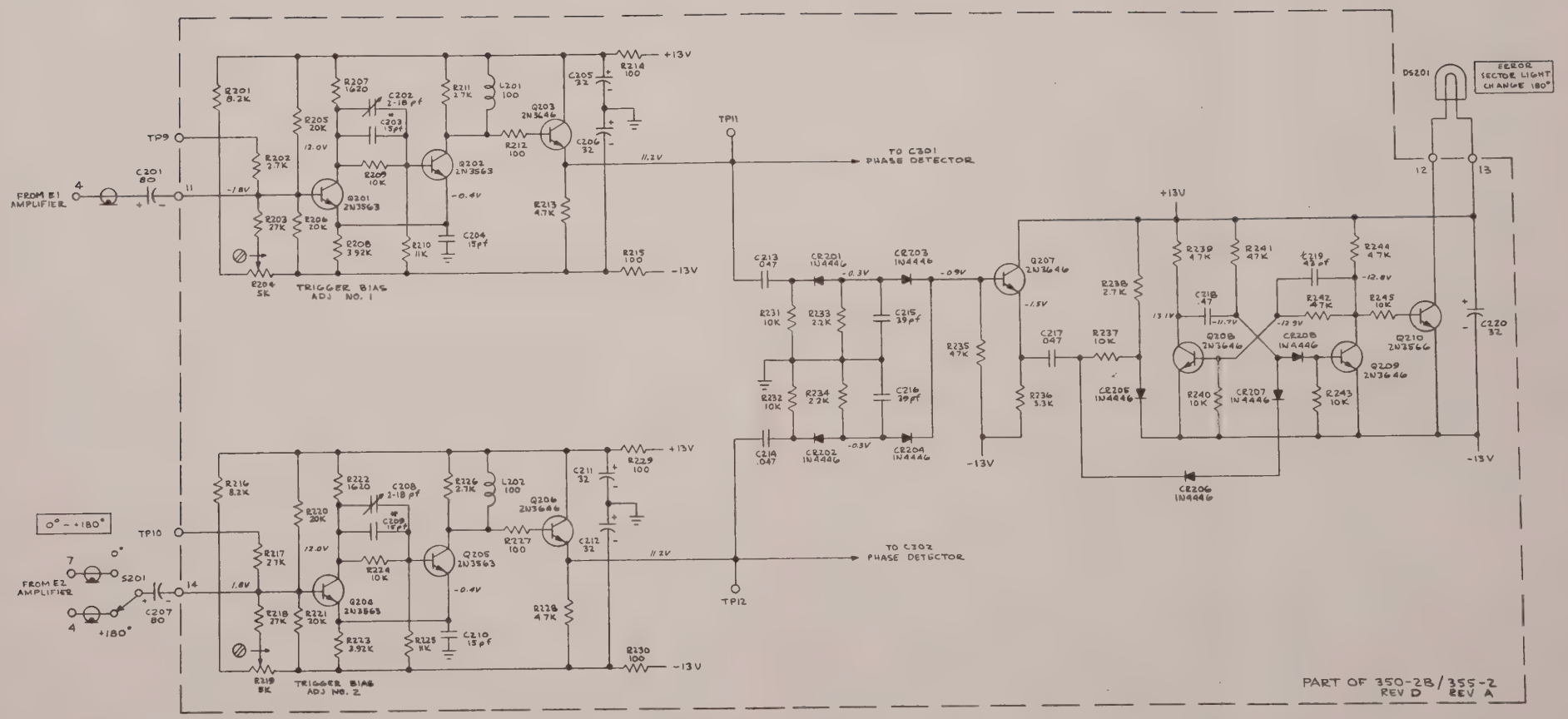
DS201	Chicago Miniature CM387
DS401	Sloan 858-R-AIC-68K
F401	.3A SB
M301	Meter ±500μA WILTRON 350-S-733
P401	Power Cord, Belden 17237-B
T401	Power Transformer, WILTRON 320-18



BOTH E1 & E2 AMPLIFIERS HAVE THIS SAME CIRCUIT WITH DIFFERENT OUTPUT CONNECTIONS AS SHOWN

NOTES:
1. UNLESS OTHERWISE MARKED
   RESISTANCE IN OHMS
   CAPACITANCE IN MICROFARADS
   * FACTORY SELECTED VALUE
2. # # CR103-CR104, CR105-CR106, CR107-CR108 ARE MATCHED PAIRS FOR VOLTAGE DROP AS PER WILTRON 350-8-808.

AMPLIFIERS AND LIMITERS



NOTES:

1. UNLESS OTHERWISE NOTED:
   RESISTANCE IN OHMS
   CAPACITANCE IN MICROFARADS
   INDUCTANCE IN MICROHENRIES
   * FACTORY SELECTED VALUE

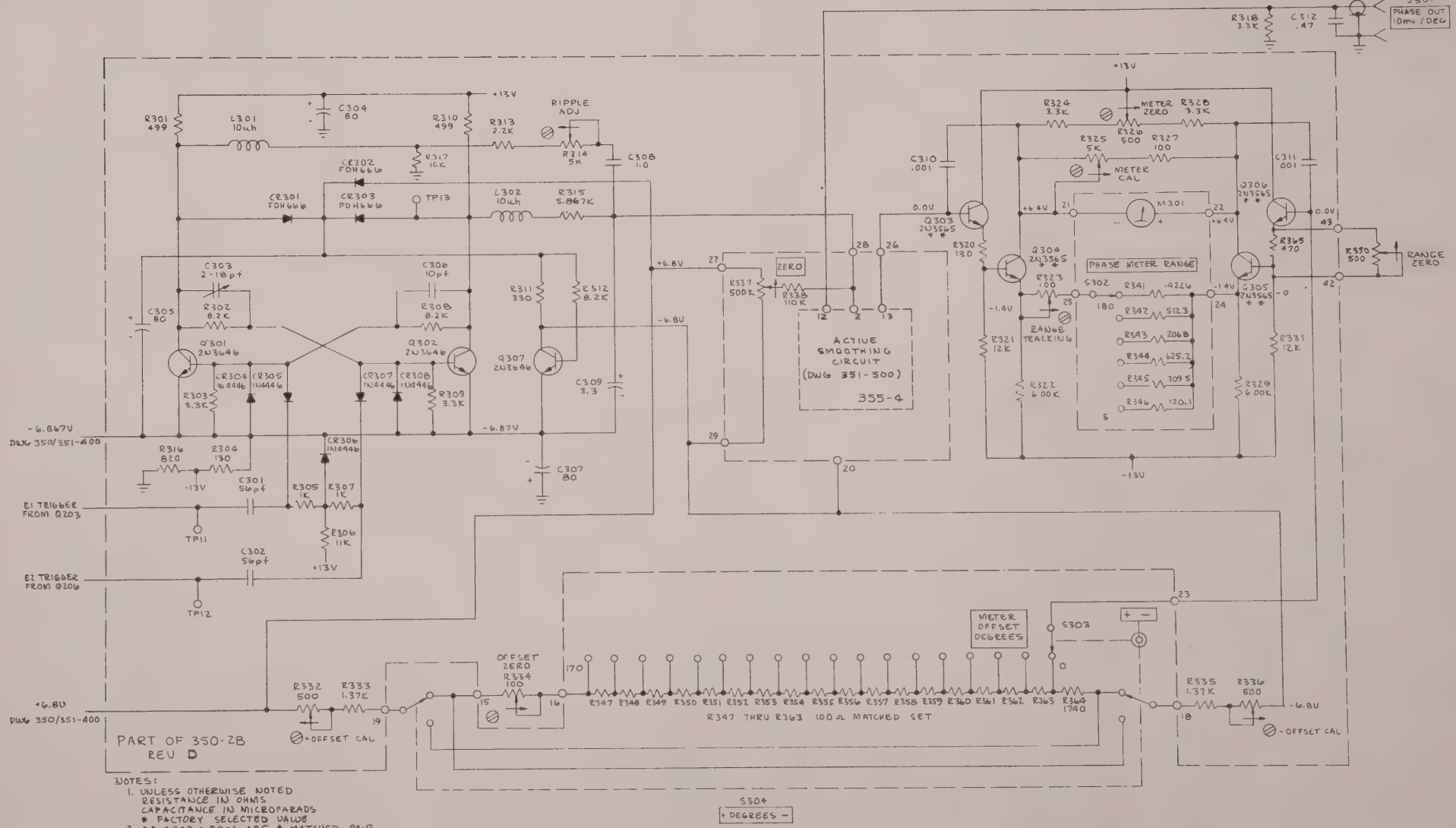
2. VOLTAGES MEASURED WITH 1 VOLT rms INPUT TO EACH CHANNEL. S101 IN 50 mv TO 100V POSITION. VOLTMETER WITH 100 MΩ IMPEDANCE USED.

PRINT: 8-70

TRIGGER CIRCUITS AND ERROR DETECTOR

350/351/355-200
9-5-69

TRIGGER CIRCUITS AND ERROR DETECTOR



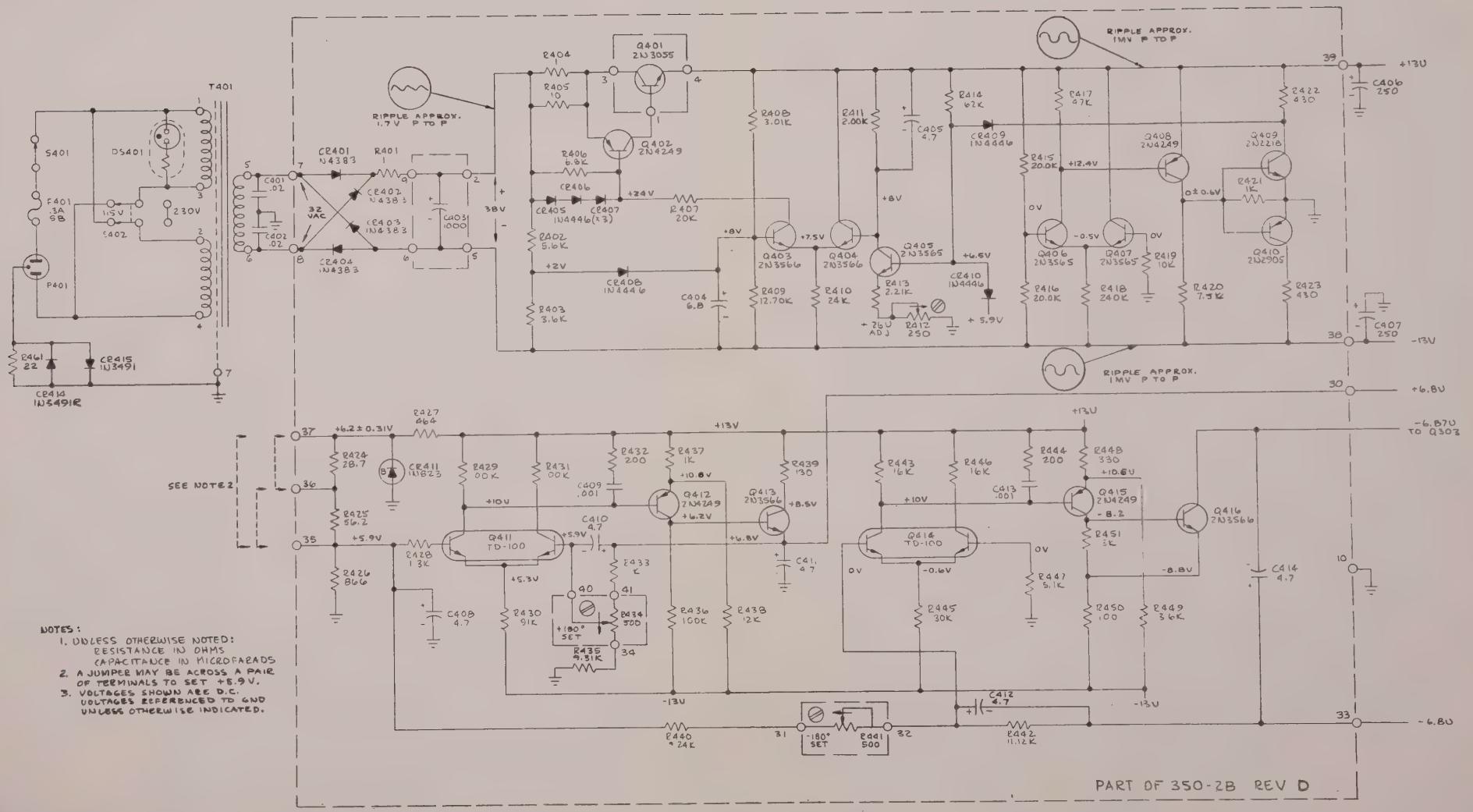
NOTES:
1. UNLESS OTHERWISE NOTED
   RESISTANCE IN OHMS
   CAPACITANCE IN MICROFARADS
   * FACTORY SELECTED VALUE
2. ** Q303 + Q306 ARE A MATCHED PAIR FOR H_{FE}. Q304 + Q305 ARE A MATCHED PAIR FOR V_{BE}.
3. VOLTAGES MEASURED WITH 1 VOLT RMS INPUT TO EACH CHANNEL S101 IN 50 MV TO 100V POSITION. VOLTMETER WITH 10 MΩ IMPEDANCE USED.

PHASE DETECTOR AND READOUT

PRINT 2-71

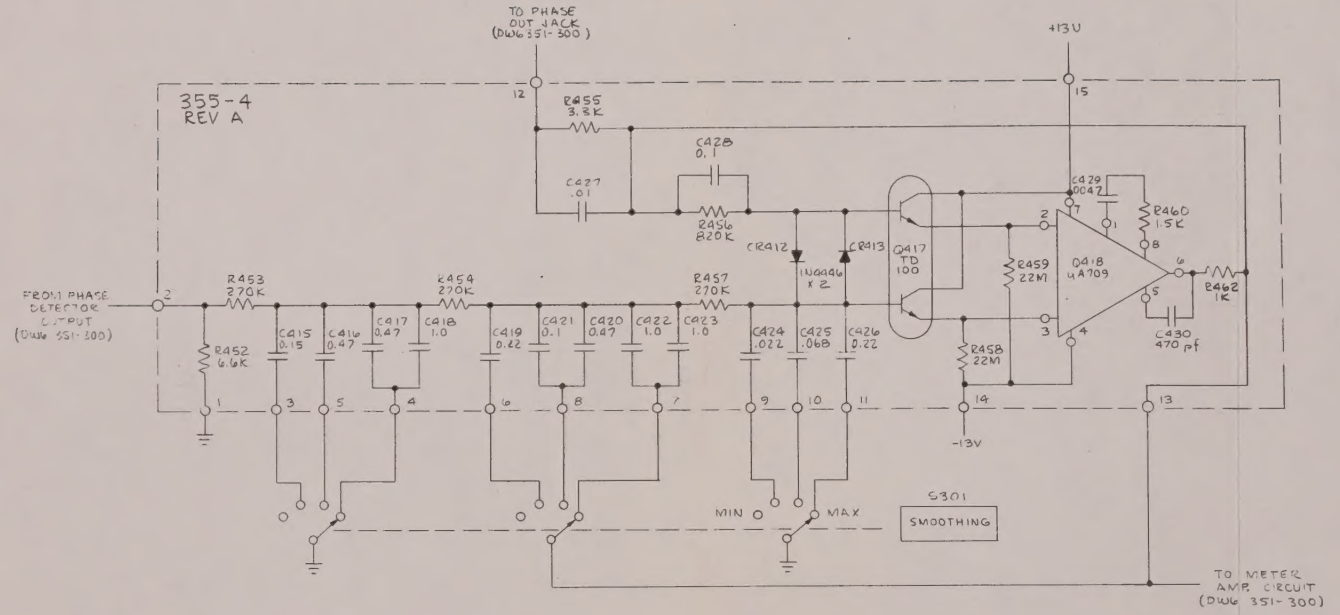
PHASE DETECTOR AND READOUT

351-300
2-17-69



NOTES:
1. UNLESS OTHERWISE NOTED:
   RESISTANCE IN OHMS
   CAPACITANCE IN MICROFARADS
2. A JUMPER MAY BE ACROSS A PAIR OF TERMINALS TO SET +5.9 V.
3. VOLTAGES SHOWN ARE D.C. VOLTAGES REFERENCED TO GND UNLESS OTHERWISE INDICATED.

POWER SUPPLY AND REGULATOR



UNLESS OTHERWISE NOTED:
RESISTANCE IN OHMS
CAPACITANCE IN MICROFARADS

PRINT: 2-71

ACTIVE SMOOTHING FILTER

351-500
10-7-70

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